Fraser River Estuary
Management Program

Status Report on Water Quality in the Fraser River Estuary 1990

Government of Canada Gouvernement du Canada

Province of British Columbia

91-06184/

FRASER RIVER ESTUARY MANAGEMENT PROGRAM

STATUS REPORT ON WATER QUALITY IN THE FRASER RIVER ESTUARY - 1990

Standing Committee on the Fraser River
Estuary Water Quality Plan

December 1990

British Columbia Cataloguing in Publication Data

Main entry under title:
Status report on water quality in the Fraser River
Estuary. -- 1987-

Triennial.
At head of title: Fraser River Estuary Management
Program.
ISSN 0836-1886

1. Water quality - British Columbia - Fraser
River Estuary. I. Fraser River Estuary Management
Program (Canada). Standing Committee on the Fraser
River Estuary Water Quality Plan. II. Fraser River
Estuary Management Program (Canada)

TD227.B7S72 363.7'3942'097112

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FRASER RIVER ESTUARY WATER QUALITY PLAN

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SUMMARY

The first Status Report on water quality in the Fraser River Estuary was based on data for the period up to 1987. This current document is the second Status Report, for the period from 1987 to 1989. The report is based on data collected by the Ministry of Environment (MoE) for checking attainment of Water Quality Objectives, joint MoE/Fraser River Harbour Commission (FRHC) monitoring, published research material from universities and agencies including the Greater Vancouver Regional District (GVRD), Department of Fisheries and Oceans (DFO) and Environment Canada, and the proceedings of two workshops held in 1988 and 1989 on water quality issues in the Fraser River Estuary.

Water quality characteristics were generally within the levels delineated by the B.C. Ministry of Environment's Water Quality Objectives. Localized areas of degradation existed in areas of limited water circulation and within initial dilution zones at effluent outfalls. Fecal coliform levels in the Main Stem were often elevated over background. The North Arm frequently exhibited areas of water quality degradation, specifically with regard to fecal coliforms, suspended solids, copper and chlorophenols. However, in general, water quality seems to be improving since the early 1980's based on concentrations of selected characteristics in fish.

Contamination of sediments is documented and appears to be localized. In general, polychlorinated biphenyl (PCB) concentrations in sediment, where measurable, have decreased since 1980. With respect to most other characteristics such as metals, the lowest contaminant concentrations were generally found in the Main Stem, the highest in the Main Arm, likely due to the particle

size of the sediments. The levels of these other contaminants found in 1987 were less than those in 1985. These latter two observations might not imply reduced contamination but sampling variability. Zinc levels in sediments were highest in the North Arm. Regarding the tributaries to the Fraser River, Still Creek had the highest sediment concentrations of cadmium, copper, lead, mercury, tin, and zinc among those tributaries that were sampled.

With respect to contaminants in biota, the highest concentrations of chlorophenols in invertebrates were found in oligochaetes in the Main Stem, pelecypods in the Main Arm, and polychaetes in the North Arm. Chlorophenol levels in chironomids, pelecypods, oligochaetes, and leeches in the North Arm, were as high as 1.0 ug/g PCP, compared to the Water Quality Objective for fish flesh of 0.1 ug/g. Chlorophenol concentrations were also high in North Arm sediments compared to the Main Arm and Main Stem chlorophenol concentrations. Considerable chlorophenol contamination was exhibited for North Arm benthos; however, these levels appear to be unchanged since 1985. As chlorophenol use continues to decline, the concentrations in the Fraser River should decrease.

The fish chosen for analyses in the 1988 survey were "resident bottom feeders", consuming invertebrates, fish eggs and insects. These types of species are thought to remain in the estuary area for considerable periods of time.

Different species of fish can behave differently to metals contamination and may accumulate different metals to differing degrees. Therefore, interspecies comparisons must be made with caution.

For fish sampled in the 1988 survey in the Fraser River Estuary, considerable variation was noted in metals concentrations between different species at the same site, and within the same species at different sites. Most variation existed between different species at the same site. Higher metals concentrations were generally found in liver rather than in muscle tissue, although chromium levels were similar in both muscle and liver tissues. Mercury concentrations in muscle tissue generally were higher than in livers. Similar findings were noted in a 1980 survey. By comparison, at Pinchi Lake (northwest from Prince George), because of a local source of mercury from mine tailings, mercury is at higher concentrations in fish livers than in muscle tissue. When this fact is considered along with the data for Fraser River fish, one may conclude that there is no significant local source of mercury in the Lower Fraser River.

In general, metals concentrations in fish muscle tissue were found to be more variable than those in livers, either within species or between species. The variability of the data indicated more monitoring effort would be required to enable conclusions to be drawn.

Some metals levels detected in muscle tissue in 1988 were lower than in 1972/73 and 1980. Based on very limited data, PCBs and organochlorine pesticides appeared to be lower in 1988 than in 1972/73; however, the age and sex of the fish were not factored in when making this tentative conclusion. When compared to different species of fish from uncontaminated lakes, Fraser River fish have similar or lower muscle tissue concentrations of metals. There are some exceptions for some species and some metals. For example, arsenic levels in all species of Fraser River fish sampled, were much higher than for fish species (Rainbow trout, Cutthroat trout, Dolly Varden, Whitefish) from "uncontaminated" B.C. lakes.

Chlorophenol concentrations in muscle tissue of lower Fraser River fish have decreased since earlier studies; however, chlorophenols are accumulating in livers. PCB levels are decreasing in fish tissues, and some phthalate esters may be accumulating in livers. Polycyclic aromatic hydrocarbons (PAHs) were detected only in North Arm fish. From the limited data available, organochlorine pesticide levels in fish have decreased since 1972/73.

Localized areas of contamination were noted on Sturgeon and Roberts banks. Chlorophenols levels in sediments were highest near the former outfall from the Iona STP in the intertidal zone of Sturgeon Bank. Nickel, iron, and chromium concentrations in sediments were relatively high at selected sites on the banks.

In Boundary Bay, B.C. Ministry of Health monitoring shows fecal coliform levels comply with Objectives for primary-contact recreation at most times between April and October. It has been suggested that the south side of Boundary Bay may have water quality conditions suitable for commercial oyster production.

Sediment analyses show that cadmium, chromium and iron at the subtidal area are higher than at intertidal sites. This may be due to smaller particle size at the former site. Organochlorine pesticides were detected at most sediment sites in Boundary Bay, with the highest concentrations at the subtidal site. PAHs and phthalates were also detected at most sediment sites, however PCBs were detected only at the subtidal site. The source of these contaminants appears to be stormwater.

The characteristics most often not meeting Objectives in rivers tributary to Boundary Bay are suspended solids, turbidity, fecal coliforms, dissolved oxygen, and nitrite. Many of the concerns with these systems are due to seasonal water flows. Problems are most likely to occur during low flow periods in summer, and during high flow flushes in the autumn when heavy loads of nutrients from farm drainage and siltation from urban areas enter the streams.

Existing monitoring programs have provided some information about the state of the estuary and uptake of contaminants. An expanded monitoring program is currently being designed which will include more characteristics and be more comprehensive.

ACKNOWLEDGEMENTS

The Standing Committee would like to thank all the speakers and workshop attendees for their participation. A special thanks goes to Dr. John Carey for his keynote address on chlorophenols discharged to the estuary.

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1.0 INTRODUCTION

During the period from 1977 to 1984, a joint Canada/British Columbia program, known as the Fraser River Estuary Study (FRES), was implemented. The FRES was the vehicle for development of a management program that would accommodate urban and economic growth but maintain the habitat productivity and water quality of the Fraser Estuary. An October 1985 agreement between the B.C. Ministry of Environment (MoE), the federal Departments of the Environment (DOE) and Fisheries and Oceans (DFO), and the North Fraser (NFHC) and Fraser River Harbour Commissions (FRHC), initiated the Fraser River Estuary Management Program (FREMP). In 1986, the FREMP Standing Committee on the Fraser River Estuary Water Quality Plan was established to provide improved coordination of water quality management.

One of the responsibilities of the Standing Committee is the development of Status Reports as necessary to assess environmental data and identify water quality issues and problems. Status Reports assist in the development and revision of monitoring and research programs in the estuary and are indicative of the effectiveness of waste management practices and control strategies.

The first Status Report was based on data for the period up to 1987. This document is the second Status Report, for the period from 1987 to 1989. The report is based on data collected by the MoE for checking attainment of Water Quality Objectives, joint MoE/FRHC monitoring, published research material from universities and agencies including the GVRD, DFO and Environment Canada, and the proceedings of two workshops held in 1988 and 1989 on water quality issues in the Fraser River Estuary.

The portion of the Fraser River included under the 1985 FREMP Agreement is that which is downstream from Kanaka Creek, including Pitt River downstream from the outlet of Pitt Lake, Sturgeon Bank, Roberts Bank, and Boundary and Semiahmoo bays (Figure 1). The following discussion will be structured according to the five sub-basins: the Main Stem from Kanaka Creek to the bifurcation at New Westminster, including the Pitt River; the North Arm from New Westminster to Sea Island; the Main Arm from New Westminster to Westham Island; Sturgeon and Roberts Banks; and Boundary and Semiahmoo bays and their tributaries. Tributaries to the Fraser River and Boundary Bay with the exception of the Pitt River are not within the study area but are discussed briefly herein.

1.1 Water Quality Objectives

Water Quality Objectives are limits set for physical, chemical or biological characteristics of water, biota, or sediment to protect designated uses. Water Quality Objectives are based upon scientifically-determined values, known as Water Quality Criteria. The application or development of Water Quality Criteria on a site-specific basis, considering designated water uses and local circumstances, leads to the development of Water Quality Objectives. The Objectives are meant as policy guidelines for use by managers in protecting water uses in specific water bodies. The Objectives can be used as a reference against which the status of water quality in a particular water body can be checked.

The scope of the Objectives is limited to characteristics which might be significantly influenced by man's activities at present or in the foreseeable future. In Tables 1 to 6, the words "not applicable" are provided for some water bodies or reaches of water bodies. This indicates that a particular characteristic will probably not be affected by man's activities in that reach or water body.

Water Quality Objectives discussed in this chapter are those published (see Tables 1 to 6) by the MoE. The Water Quality Objectives are MoE policy for guiding the protection and use of the specific water body. It should be noted that MoE does not require that Objectives (except Objectives for PCBs and chlorophenols in fish tissue) be met within initial dilution zones extending up to 100 metres from point source discharges (Ministry of Environment 1986). Criteria referenced are from the MoE, the Canadian Council of Resource and Environment Ministers (renamed the Canadian Council of Ministers of Environment), the U.S. Environmental Protection Agency (EPA), and other sources. All metals data and related Objectives are for total metals unless otherwise specified.

Provisional Objectives are set where the information available about local conditions (e.g., water quality, water uses, aquatic life, waste discharges) and/or the Water Quality Criteria for a substance are inadequate for the establishment of permanent Objectives. Short-term and long-term Objectives may be used where existing water quality does not suit all desired water uses, and it is feasible to improve the water quality over time. At this time, the B.C. MoE Water Quality Objectives are provisional.

Through FREMP, a mechanism has been adopted to develop and revise Water Quality Objectives for the study area with the cooperation and approval of the five signatory agencies (Standing Committee on the Fraser River Estuary Water Quality Plan, in prep.). This approval process has been used for preparation of Objectives for the Pitt River area.

1.2 Monitoring Limitations

There are limitations inherent in any ambient monitoring undertaken in a system as complex as the Fraser River Estuary. For example, it is sometimes not feasible with existing resource constraints to monitor locations at an optimal frequency. Historically only main channel areas have been monitored, and other areas such as sloughs and side-channels have received a nominal monitoring effort. Analytical capabilities improve continually, providing evidence of problems which were not recognized in the past. Characteristics for which there are no Objectives are being measured to broaden existing data bases.

No quality assurance (QA) program is in place for many of the studies referenced herein, although there are some notable exceptions (Swain and Walton 1988, Swain and Walton 1989). Therefore, many of the conclusions are preliminary and non-conclusive. Plans are under way at present to implement QA programs for several programs, but generally lack funding and staffing.

2.0 STATUS OF WATER QUALITY IN THE ESTUARY

The most extensive review to date of Fraser River water quality took place during the Fraser River Estuary Study (1970 to 1978). A series of technical reports dealing with discrete topics such as water chemistry, bacteriological water quality, and industrial discharges was issued in 1979 and in the early 1980's. A summary report incorporated the major findings of the technical reports (Water Quality Work Group, 1979). Swain and Holms (1985, 1988) updated the Fraser River Estuary Study findings in two technical reports, which included provisional Water Quality Objectives. A third report (Swain 1989) set out Objectives for lower Fraser River tributaries. The 1987 FREMP Status Report (Standing Committee 1987) presented the most up-to-date monitoring information.

Since 1986, a number of studies have been carried out in the lower Fraser River which are not specific to a particular site or reach.

In 1987/88, Krahn et al.initiated a four month study of five sawmills and two export terminals on the lower Fraser River. Leachate from lumber stacks and yard runoff was analyzed. Wood treatment facilities examined included diptanks and low- and high-pressure spray systems. Dipped lumber leached up to 158 000 ug/L chlorophenols (CPs) and generated runoff with up to 6 600 ug/L CPs. Low-pressure sprayed lumber leached up to 576 000 ug/L CPs and high-pressure sprayed lumber leached 9 800 ug/L, with yard runoff containing up to 1 968 ug/L CPs. Weather conditions varied during the study. Leaching from lumber stacks occurred after 1.0 to 1.5 mm continuous rainfall.

Rainbow trout LT50 bioassays were performed using stormwater samples from two of the sites. Effects were noticed upon introduction of the effluent, and all fish died within 40 to 120 minutes. The reported median concentration range of 32 to 130 ug/L total CPs which is acutely toxic to salmonids was exceeded in final stormwater discharges from all of the storage yards studied during precipitation events.

Studies by Levings (1989) on fish utilization in the estuary enhance our capability to assess the implications of these stormwater discharges. Servizi et al. (1988) documented contamination by CPs in fingerling chinook from the Fraser River. Whole body tissue contained 7.6 ng/g tetrachlorophenol (TTCP) and 24.4 ng/g pentachlorophenol (PCP). Salmon exposed to chlorophenols quickly reach an equilibrium with their aquatic environment and maintain that level of contamination without further bioconcentration.

Swain and Walton (1988) reported on sediment data collected at a number of sites in the Estuary. Some of their key findings which could relate to other locations, but also specifically to the Estuary are noted below.

The F- and t- test results indicated that the variability of the sediment data collected by sampling at a fixed point did not change significantly (P=0.05) when the number of replicate samples was reduced from ten to three for 87% of the samples collected. At no site were more than five replicates required (Swain and Walton 1988) before there was no significant difference between the mean of five samples or the mean of ten samples.

Intra-site variability seems to be less important than inter-site variability of sediment data. In future surveys of sediment quality, it was recommended that fewer replicate samples be collected at each site, and that a larger number of sites should be sampled (Swain and Walton 1988).

Finally, to note that sediments of smaller particle size sorb higher levels of contaminants compared to sediments of larger sized particles per unit volume is useful when comparing sediments from different water bodies.

2.1 FRASER RIVER MAIN STEM AND TRIBUTARIES

2.1.1 The Tributaries

The four major tributaries to the Lower Fraser River are Kanaka Creek; the Pitt, Alouette and North Alouette rivers; the Coquitlam River; and the Brunette River. The Pitt and Alouette watersheds are essentially rural with large bodies of slow moving waters and seasonal flow variations. In contrast, the Brunette system is urban in nature, with lake storage, seasonal flow and temperature fluctuations, and urban stormwater inputs.

Water Quality Objectives have been prepared for these tributaries (Swain 1989), and are summarized in Table 6. Most of the Water Quality Objectives for these streams are being achieved. Where that is not the case, long-term Objectives are proposed by the B.C. MoE for future compliance.

2.1.1.1 Water

The pH in all tributaries is generally slightly acidic, although in the lower reaches of the Coquitlam River, neutral pH values were documented. Total chromium, copper, iron, and lead values in some of the water samples exceeded aquatic life criteria in Kanaka Creek, the Pitt, Alouette and North Alouette rivers. In the Coquitlam River, iron, manganese, aluminum, and copper values exceed aquatic life criteria. These values are believed to be high due to the presence of urban runoff in these systems. In the Brunette River, aluminum, chromium, copper, iron, lead, mercury, and zinc values exceeded aquatic life criteria. Some of these values are naturally occurring, but others are due to anthropogenic activity.

Nitrite, nitrate and ammonia levels were low in all systems except the Brunette River. Ammonia and nitrite concentrations in the Brunette River were elevated with respect to other streams, but were below aquatic life criteria. Phosphorus levels were high enough to cause algal blooms in Kanaka Creek and the Alouette and North Alouette rivers. Phosphorus concentrations increased in a downstream direction in the Coquitlam River. Burnaby Lake phosphorus concentrations exceeded the upper level recommended for optimal salmonid production (Nordin 1985).

Dissolved oxygen levels in Kanaka Creek were often low, associated with algal blooms. Dissolved oxygen levels were high and thus adequate in upstream reaches of the Alouette and North Alouette rivers and throughout the Pitt River, in Pitt and Alouette lakes, and in the Coquitlam River. In the Brunette River, dissolved oxygen concentrations were low, while in Still Creek and Burnaby Lake dissolved oxygen concentrations were below aquatic life criteria.

Dissolved and suspended solids were generally low throughout the Pitt, Alouette, and North Alouette rivers. Suspended solids were often high in the Coquitlam River and may be occurring naturally or as a result of runoff from a gravel operation. Levels of suspended solids were high throughout the Brunette system and were likely the result of stormwater discharges. Fecal coliform levels were suitably low to allow for primary-contact recreation in Kanaka Creek, Alouette and Pitt lakes, and the Coquitlam River. Fecal coliform levels comparatively were higher in the Alouette and Pitt rivers. In the Brunette system, fecal coliform levels exceeded primary-contact recreation criteria (MoE 1989).

2.1.1.2 Sediment

In November 1987, a survey of bed sediments was conducted at four sites in the Pitt River as follows: one site at the mouth of the Alouette River, two sites in each of the Brunette and Coquitlam rivers, and one site each on Kanaka and Still creeks. Contaminant levels in sediments were related to particle size. Since finer material has a larger surface area per unit volume to which contaminants can be more easily sorbed, higher contaminant levels are expected with smaller particle size sediments. The largest mean particle size was found at the Brunette and Coquitlam rivers, and in Kanaka and Still creeks. The smallest mean particle size was found at two sites on the Pitt River; near its mouth and upstream from the Alouette River confluence.

The smallest mean particle size was found at the mouth of the Pitt River and, as expected, the highest metal values were detected there. The lowest metal levels were associated with the coarse sediments at the Brunette River site. As would be expected for an urban drainage basin, lead concentrations were elevated throughout the Brunette River system, (52.9 and 90.6 ug/g dry-weight), as were levels of zinc (83.1 and 128 ug/g dry-weight) compared to levels in the other tributaries. Concentrations of nickel were higher in the Alouette River system, compared to similar particle sized sediments in the Pitt River (Swain and Walton, 1988).

Still Creek sediments showed high levels of contamination for cadmium (1.18 ug/g), copper (122 ug/g), lead (238 ug/g), mercury (0.12 ug/g), molybdenum (26 ug/g), tin (5.31 ug/g), and zinc (256 ug/g) (all dry-weight). This level of zinc is similar to that previously found in sediments adjacent to the former outfall from Iona STP. When compared to similar particle size sediments from Kanaka Creek, copper at Still Creek is ten times higher, cadmium almost ten times higher, and mercury is seven times higher. While lead and zinc levels were elevated throughout the Brunette system, high cadmium and mercury levels seem to be restricted to Still Creek. The highest values for total volatile residue and organic carbon were also found in Still Creek. Tin and molybdenum were detected only in Still Creek sediments (Swain and Walton, 1988). Polychlorinated biphenyls (PCBs) and chlorophenols were below detection limits at all sites.

2.1.1.3 Biota

No recent sampling of biota has been carried out on these Fraser River tributaries.

2.1.1.4 Conclusions

From the available data, localized contamination of sediment and water in Still Creek and the Brunette River is apparent. All other tributaries within the study area appear to be in relatively good condition.

2.1.2 Fraser River : The Main Stem

2.1.2.1 Water

The Main Stem was not sampled to check attainment of Water Quality Objectives in 1986. In 1987, all of the Objectives checked were achieved except at a site downstream from the West Langley Sewage Treatment Plant (STP) discharge. For this location, dissolved oxygen concentrations were below the Objective for the minimum concentration of 7.75 mg/L on two of the five dates (7.5 and 7.4 mg/L) (MoE, 1988). In 1988 and 1989, all dissolved oxygen levels met Objectives; however, the West Langley site was not checked (MoE, 1989; MoE, 1990).

In 1988, the Objective for the maximum fecal coliform level of 400/100 mL to protect primary-contact recreation was met, but the Objective for the geometric mean of 200/100 mL was exceeded at most sites during the May to September sampling period (MoE, 1989).

In 1988, chlorophenols were sampled in water in Sapperton Channel and downstream from Barnston Island. The results were classed as "indefinite" since the detection limit for each of the chlorophenol isomers, when added, was greater than the Objective level. Better detection limits are required if compliance with the Objective is to be confirmed.

2.1.2.2 Sediment

In January 1987, each of the three reaches of the Fraser River was sampled for metals, PCBs, and chlorophenols in sediments and benthos. In each reach, two sites were sampled with ten replicate surface grabs of sediment. Five other sites in each reach were sampled by single surface grabs. In November 1987, one site downstream from Barnston Island was sampled in conjunction with a sampling program on the Fraser River tributaries.

Based on the percentage of particles that passed the 400 mesh size, the particle size of sediments from the Main Stem was more coarse than either the Main or North arms, and coarser than samples taken from the same two sites on the Main Stem in a 1985 study. Since finer material has a larger surface area to which contaminants can be sorbed, it is anticipated that higher contaminant levels would be found in sediments with smaller particle size. Thus, the 1987 contaminant levels were expected to be lower than the 1985 levels, and this was generally the case (Swain and Walton, 1988).

Most levels in sediments in 1987 were lower than in 1985, including cobalt, chromium, copper, iron, manganese, nickel, strontium, vanadium, zinc, total volatile residue, carbon, and phosphorus. Mercury levels remained about the same as in 1985, <0.05 to 0.130 ug/g (dry-weight). Lead values appeared to increase in 1987 to as high as 30 ug/g (dry-weight) from about 20 ug/g (dry-weight) in 1985 (Swain and Walton, 1988).

Statistically significant lower values (P=0.05) were found in 1987 based on the F-test and Student's t-test for the same sites between 1987 and 1985, were noted for 6 of 14 characteristics at Barnston Island, and 10 of 14 characteristics at Sapperton Channel. This was probably due to the coarser sediments found in the 1987 survey (Swain and Walton, 1988).

In 1985, PCBs were detected adjacent to Barnston Island (Swain and Walton, 1988). Total PCBs in sediments were less than the 0.02 ug/g wet-weight detection limit at all sites in 1987 (MoE, 1988).

In the 1988 monitoring to check achievement of Objectives, PCBs were less than the 0.01 ug/g maximum Objective (MOE 1989). These limited data indicate that there may be a decrease in PCB concentrations in sediments.

PCP was detected in sediments at one site, and TTCP was detected at two sites in 1987 (MoE, 1988). When converted to dry-weight, all levels were below the 0.01 ug/g Objective. This appears to represent a decrease from 1985 chlorophenol levels in Fraser River sediments. The 1988 and 1989 chlorophenol sampling to check achievement of Objectives were reported as "indefinite" (MoE, 1989; MoE,1990), due to the problem with detection limits for the three isomers when added being greater than the Objective.

Analyses of organochlorine pesticides were not conducted for the January 1987 samples. Of 18 organochlorine pesticides tested for, only dieldrin (0.009 ug/g dry-weight) was detected in the November 1987 sample from Barnston Island.

2.1.2.3 Biota

In 1987, eight taxa of benthic organisms were collected at two sites in each reach of the Fraser River. Amphipods, chironomids, crustaceans, dipterans, leeches, oligochaetes, pelecypods, and polychaetes were tested for PCP, TTCP, and trichlorophenol (TCP). Among the highest concentrations detected were in oligochaetes (4.2 ug/g PCP, 3.0 ug/g TTCP, 2.0 ug/g TCP, wet-weight), and in lampreys (3.2 ug/g PCP, 0.5 ug/g TTCP, ND TCP, wet-weight) at Barnston Island. In contrast the highest values found in the Main Arm were in pelecypods (2.5 ug/g PCP, 1.5 ug/g TTCP, 0.4 ug/g TCP, wet-weight), while in the North Arm the highest values were found in polychaetes (1.0 ug/g PCP, 1.0 ug/g TTCP, 0.2 ug/g TCP, wet-weight). The 1985 survey detected chlorophenols in only a few organisms. It is not known how much an influence gut contents had on organisms such as oligochaetes.

Concentrations in chironomids in 1987 at Barnston Island (0.08 ug/g PCP, 0.04 ug/g TTCP, <0.02 ug/g TCP, wet-weight) were slightly higher than 1985 levels (0.06 ug/g PCP, 0.03 ug/g TTCP, wet-weight). Chlorophenol concentrations in lampreys at Barnston Island showed larger increases, from 0.5 ug/g PCP in 1985 to 3.2 ug/g PCP in 1987 and from <0.1 to 0.5 ug/g TTCP (wet-weight) (Swain and Walton, 1988). From these data, it would appear that chlorophenols in benthic organisms may be increasing, although a broader data base is required for a conclusive determination.

In August 1988, fish from one site downstream from Barnston Island were tested for metals and organic contaminants in muscle and liver tissue. The total chlorophenols in muscle were below the 0.01 ug/g wet-weight Objective and appear to have decreased considerably for the same species since 1980. Inter-species variability in concentration was evident. TCP in the muscle tissue of peamouth chub was significantly greater than in northern squawfish or largescale sucker. Chlorophenol concentrations in liver were more difficult to compare with those reported in previous studies, due to different detection limits and analytical methods. Chlorophenols appear to be accumulating in fish livers (Swain and Walton, 1989).

Of the phthalate esters analyzed, butyl benzyl and bis (2-ethylhexyl) phthalate concentrations were highest in fish muscle tissue collected from the Main Stem, when compared to the same species from the North and Main arms. Five phthalate esters were detected in fish livers. While the data base was insufficient for firm conclusions, it appears that three of these phthalates were accumulating in the fish livers (Swain and Walton, 1989).

Polycyclic aromatic hydrocarbons (PAHs) were detected in livers but not in muscle tissue of fish from the Main Stem. This indicates that PAHs may be accumulating in fish livers (Swain and Walton, 1989).

While organochlorine pesticides were detected in muscle tissue in Main Stem fish, significant variation occurred between data sets for the three species studied, making statistical analyses unreliable (F-test; P=0.05). In general, the concentration of organochlorine pesticides in fish muscle appears to have decreased since 1973. Concentrations of organochlorine pesticides in fish livers were higher than those in muscle tissue. DDD and DDE were found more frequently in fish livers than muscle from all species, at most sites (Swain and Walton, 1989).

Metal levels in liver and muscle tissues in Fraser River fish were generally lower than in fish tissues from uncontaminated lakes. Copper concentrations in muscle tissue varied widely. Different species had higher concentrations in each reach. For largescale suckers the highest copper concentration was from Main Stem fish (mean 0.33 ug/g, compared to a mean of 0.27 ug/g in the Main Arm, and 0.20 ug/g in the North Arm) (Swain and Walton, 1989).

In 1988, mean zinc concentrations in muscle tissue of Main Stem fish were similar to those found in 1972/73 and in 1980; however, the maximum values were lower in 1988 than in the other two years. The highest zinc value for Main Stem fish muscle was from redside shiners (30.5 ug/g). This level is about five times greater than that for fish from uncontaminated lakes (Swain and Walton, 1989).

2.1.2.4 Conclusions

Water Quality Objectives generally are being met in the Main Stem for all characteristics except fecal coliforms. Detection limits for chlorophenols in water need to be improved before Objectives levels can be checked definitively.

Concentrations of PCBs and chlorophenols in sediments appear to be decreasing. Detection limits for chlorophenols must be improved. Most metal concentrations in sediments were lower in 1987 than in 1985; however, lead values appeared to increase.

From the limited data base, it appears that chlorophenol concentrations in invertebrates are increasing. Concentrations of chlorophenols and organochlorine pesticides in fish tissues have decreased since 1973. Mean metal concentrations in fish tissues in 1988 remain similar to levels measured in previous years' sampling programs.

2.2 FRASER RIVER: MAIN ARM

Data for this reach of the Fraser River are collected on a yearly basis by the GVRD as part of their permit requirements for the discharges from the Annacis and Lulu STPs. The MoE have also done some monitoring related to discharges, and in conjunction with the Fraser River Harbour Commission, have done some special studies on effluents, sediments, fish, and benthic organisms. Inland Waters have done one study examining sediment toxicity, and the Department of Fisheries and Oceans did a special study in Deas Slough.

2.2.1 Water

Fecal coliforms at stations near Annacis Island and Lulu Island in the Main Arm in 1986 were below the Objective for the maximum of 4 000 /100 mL for the period from April to October. The frequency of monitoring was inadequate to determine if Objectives for the average concentration were met. The averages are to be based on five-weekly samples being collected within 30 days (Rocchini, 1987). In 1987, Objectives for fecal coliforms were exceeded in samples collected opposite Annacis and Lulu islands, and Steveston (MoE, 1988). During 1988 and 1989, fecal coliform Objectives were exceeded each year on two occasions at the same three sites (MoE, 1989; MoE, 1990).

Objectives for dissolved oxygen were occasionally not met in 1987 at a site downstream of the Annacis Island STP (MoE, 1988). In 1989, samples collected near the bottoms of Gunderson, Deas, and Ladner sloughs occasionally were not high enough so that the Objective could be achieved (MoE, 1990).

In 1986, one value (0.020 mg/L) for total lead collected at a site upstream from the Lulu Island STP exceeded the Objective of 0.010 mg/L. All GVRD data for dissolved metals were below the maximum Objective for total concentrations (Rocchini, 1987). In 1987, total copper (0.040 mg/L) and total lead (0.40 mg/L) concentrations exceeded Objectives levels upstream and downstream from the Lulu Island STP (MoE, 1988). In 1987, zinc exceeded the Objective upstream from the Lulu Island STP, with a maximum value of 0.570 mg/L (MoE, 1988). Total lead, copper, and zinc concentrations in 1988 were low enough so that the Objectives levels were achieved (MoE, 1989). These data in each year were not collected with sufficient frequency that these differences among years may be attributable to flows or suspended solids.

During 1986-87, six major industrial and municipal discharges to the Main Arm were the subject of a special MoE/FRHC study. Periodic acute toxicity of effluents was documented at two metal finishing operations using rainbow trout fish bioassays. Noranda Metals (now Wolverine Tube), which at the time provided no wastewater treatment, had the most toxic discharge, with a range of 96-h LC50 values of 5.6-44 % in static tests. The characteristics of concern were copper, zinc, oil and grease, and acidic pH. The estimated discharge from Noranda Metals to the Main Arm was 500 to 1 000 m^3/d . Elevated concentrations of copper and oil and grease over background could be measured 100 m downstream from the discharge.

The cooling water discharge at Titan Steel contained contaminants at levels considered acutely toxic to fish, notably dissolved zinc at concentrations of 0.17 to 0.57 mg/L. Major plant modifications were scheduled for 1987, and efforts were made to improve the discharge. Effluents from LaFarge Cement and Chatterton Chemicals were non-acutely toxic. No increases over background were noted in the river below Chatterton; however, oil and grease concentrations 100 m downstream from LaFarge were 5 mg/L over background.

2.2.2 Sediment

All values discussed are as dry-weight unless otherwise stated.

In a 1987 survey of the three main reaches of the river below Kanaka Creek, the smallest sediment particle size was found in the Main Arm. This corresponded with the results of a 1985 study.

Aluminum levels (13 000 ug/g) were highest in the Main Arm in comparison to the other two reaches. This was expected, as higher contaminant concentrations coincide with smaller particle size. There was no statistically significant difference between the 1987 aluminum levels and those found in 1985. Total chromium levels were highest in Main Arm sediments, with a mean concentration of 34.8 ug/g, which is not statistically different from the 1985 level of 36.3 ug/g (Swain and Walton, 1988).

Concentrations of copper, iron, and manganese in sediments increased from the upstream site to the downstream site, as was found in 1985. This is not unexpected since the sediment particle size at the downstream site was finer than at the upstream. Copper levels were significantly lower in 1987 than those reported in 1985; however, they were higher than the results from a 1980 study. Iron values in 1987 were lower than those in 1985 or 1980. Manganese concentrations in sediments in 1987 (542.2 and 624.9 ug/g) were higher than those in 1985 (520 - 590 ug/g) or those in 1980 (216 309 ug/g) (Swain and Walton, 1988).

Mercury values in sediments for 1987 were slightly higher than 1985 levels (0.071 compared to 0.06 ug/g) reported for the Annacis channel site. Nickel concentrations in sediment in 1987 (37.8 - 40.6 ug/g) were significantly lower than those in 1985 (41.3 - 43.3 ug/g) except at Ewen Slough. Zinc values were significantly lower in 1987 (63.4 - 73.5 ug/g) than those found in 1985 (mean approximately 70.0 ug/g). These differences are likely due to the smaller particle size sediments obtained in 1985 (Swain and Walton, 1988).

Total volatile residues in sediments appeared to increase slightly in the 1987 sediment samples when compared to those from 1985 (4.3 - 6.4 % compared to 4.8 - 5.5 %). Total carbon was higher in the Main Arm sediments than those from the Main Stem or North Arm, with the 1987 levels considerably lower than those in 1985. Mean phosphorus levels in 1987 (715 - 723 ug/g) were less than those of 1985 (733 - 772 ug/g). This apparent reduction in sediment phosphorus levels was most evident at Ewen Slough (Swain and Walton, 1988).

Aluminum, barium, chromium, copper, iron, manganese, mercury, nickel, strontium, zinc, total volatile residue, total carbon, and phosphorus varied significantly (F-test; P=0.05) between the upstream and downstream sites in the Main Arm, thus the mean values could not be compared using further statistical tests (Swain and Walton, 1988).

2.2.3 Biota

In the 1987 study, the highest chlorophenol levels in benthic organisms in the Main Arm were in pelecypods (2.5 ug/g wet-weight PCP; 1.5 ug/g wet-weight TTCP; and 0.4 ug/g wet-weight TCP). This finding represents an apparent increase of chlorophenol concentrations compared to data from 1985. At Ewen Slough, PCP in polychaetes between 1985 and 1987 appeared to increase from 0.04 to 0.2 ug/g; and TTCP appeared to increase from 0.07 and 0.2 ug/g (Swain and Walton, 1988). From these limited data, it would appear that chlorophenol levels in benthic organisms may be increasing, as was the case in the Main Stem.

Tuominen et al. (1988) compared different toxicity tests to assess the quality of water and sediment which included using the nematode Panagrellus redivivus. Of the four sediment samples taken near Chatterton Chemicals, one was highly toxic to the worms. One of the four samples from Purfleet Point (Annacis Island) also caused acute toxicity. In all cases, sediment extracts prepared using water were more toxic than those prepared using methanol, indicating that the toxic component was polar.

In August 1988, fish collected in Ewen Slough were analyzed for metals and organic contaminants in both muscle and liver tissues. The Objectives for PCBs in fish muscle were achieved. The highest concentrations of PCBs in fish livers, for each species, occurred in fish from the North Arm, except for starry flounder livers. Starry flounder livers from the Main Arm had the highest PCB concentration (0.52 ug/g wet-weight). For PCBs in muscle tissue, northern squawfish, peamouth chub, staghorn sculpin, and starry flounder from the Main Arm had higher concentrations than the same species caught in the other reaches. Based on limited data, PCB levels in fish tissue appear to have decreased in 1988 compared to the 1972/73 or 1980 surveys (Swain and Walton, 1989).

From the available data for fish captured in the Main Arm, it appears that some phthalates and chlorophenols may be accumulating in fish livers. PAHs were not detected in fish muscle tissue. PAHs were detected in fish liver tissue, up to a maximum of 0.12 ug/g (wet-weight), which may indicate accumulation in livers. There was no apparent difference in PAH concentrations within fish species or between fish from the North and Main Arms (Swain and Walton, 1989).

In general, the levels of organochlorine pesticides in fish muscle tissue appeared to be lower in 1988 than those from a 1972/73 study. DDD and DDE were detected frequently in fish livers from all species at most sites. The highest DDD value was 0.05 ug/g (wet-weight) in a largescale sucker from the Main Arm. Gamma-chlordane, DDT, endrin, and endosulfan I levels were generally higher in Main Arm fish livers. Within the Main Arm sample area, the level of DDE in the livers of largescale sucker was significantly lower than in peamouth chub or northern squawfish (Swain and Walton, 1989).

The highest mean arsenic concentrations in fish muscle tissue were found in samples from the North and Main arms. Peamouth chub and starry flounder from the Main Arm had the highest levels of arsenic in muscle tissue (0.11 ug/g and 0.25 ug/g wet-weight, respectively) compared to the same species taken from North Arm and Main Stem sites. Mean arsenic concentrations in livers were highest in the Main Arm for largescale suckers (0.129 ug/g wet-weight) compared to the other river sampling sites. For all fish species sampled, arsenic concentrations in muscle and liver were two or more times greater in Fraser River fish than in fish from "uncontaminated" lakes. Although detection limits in previous studies were much higher, thereby making comparisons difficult, it appears that arsenic concentrations in fish muscle and liver tissues have decreased since 1980 (Swain and Walton, 1989).

Copper levels in fish muscle tissue appear to have decreased from 1972 to 1980; but 1988 levels were similar to those of 1980. The highest mean value of copper in fish muscle tissue was in northern squawfish from the Main Arm (0.34 ug/g, wet-weight), compared to 0.32 ug/g (wet-weight) in the same species from the Main Stem or 0.24 ug/g (wet-weight) in the North Arm (Swain and Walton, 1989).

According to 1988 data, the mean concentration of manganese in muscle tissue of starry flounder (9.59 ug/g wet-weight), and in livers of largescale suckers (15.2 ug/g wet-weight), was considerably higher than in fish from "uncontaminated" lakes. Manganese in livers was five to ten times higher than in muscle tissue. Both these trends are similar to what was found in the 1980 study (Swain and Walton, 1989).

In 1988, mean zinc concentrations in muscle tissue of peamouth chub were substantially lower than previous values from 1972/73, while zinc levels in northern squawfish and largescale sucker muscle tissue were slightly less than those in 1972/73. The zinc content of starry flounder muscle tissue (26.9 ug/g, wet-weight), was about five times higher than found in fish from "uncontaminated" lakes. Zinc in the livers of staghorn sculpins (63.9 ug/g wet-weight) was about twice that reported for fish from "uncontaminated" lakes (Swain and Walton, 1989).

Birtwell et al. (1987) studied salinity, dissolved oxygen, temperature, redox potential, and the annual distribution of sockeye underyearlings in Deas Slough. Localized areas of low dissolved oxygen occurred occasionally in deep water pockets. In the upper reaches of Deas Slough, temperature was occasionally elevated (e.g., 23°C), and dissolved oxygen was reduced to levels known to be stressful to salmonids (<4.0 mg/L) and possibly lethal. The observed variations seemed to have little effect on the horizontal distribution of the sockeye in Deas Slough. The "high apparent growth rate" and condition factor of juvenile sockeye in Deas Slough implied a value to their temporary residence in from late spring through summer (Birtwell et al. 1987a).

2.2.4 Conclusions

Water Quality Objectives for fecal coliforms were frequently exceeded downstream from the Lulu Island and Annacis Island STPs at times when effluent chlorination was occurring. Metal levels upstream and downstream from the Lulu Island STP exceeded Objectives in 1986 and 1987; however, all metals values were below Objectives in 1988.

Concentrations of mercury in sediments apparently increased at some sites from 1985 to 1988. Copper, iron, nickel, and zinc levels appeared to decrease, while chromium concentrations in sediments were similar to those in 1985.

Concentrations of chlorophenols in benthic organisms in the Main Arm appeared to increase over the 1985 to 1987 period.

Based on limited data, PCB and organochlorine pesticide levels in fish tissue appeared to be lower in 1988 than in previous surveys; however, some phthalates, PAHs, and chlorophenols in fish livers were higher. Arsenic levels in fish tissue, while relatively high in 1988, appeared to have decreased since 1980. Zinc concentrations in fish muscle apparently have decreased since 1972/73.

2.3 FRASER RIVER: NORTH ARM

2.3.1 Water

Fecal coliform levels were monitored on only one occasion in 1986. All three sites checked were below the 4 000 /100 mL Objective for the maximum concentration for the protection of irrigation water supplies which applies during the irrigation season only (Rocchini, 1987). In 1987, fecal coliform Objectives were frequently exceeded at Mitchell Island, at the Oak Street Bridge site, and at Sea Island (MoE, 1988). The 1988 monitoring showed that the fecal coliform Objective was met at all sites (MoE, 1989). This apparent improvement may be related to the changes made in the

Vancouver South Slope sewer system at the end of 1986 and in 1987 (B. Jones, pers. comm.). On one occasion in 1989, the fecal coliform Water Quality Objective for maximum concentrations was exceeded near Sea Island (MoE, 1990).

Objectives for dissolved oxygen in the main river channels were achieved in 1986 (Rocchini, 1987), 1988, and 1989 (MoE, 1989; MoE, 1990). In 1989, samples collected near the bottom of MacDonald Slough were lower than the Objective (MoE, 1990). In 1987, the Objective occasionally was not met at the sites along the North Arm Jetty (MoE, 1988). Values for dissolved oxygen in 1987 ranged from 6.6 to 7.5 mg/L on October 20 at the Jetty, and were 7.1 mg/L at a site upstream from Scott Paper on both September 3rd and 16th (MoE, 1988), but similar low values have not been measured in subsequent years.

Apparent fluctuations of suspended solids in the North Arm may reflect sampling variability. Suspended solids Objectives apply only to the North Arm. In 1986, suspended solids levels exceeded Objectives on two occasions (Rocchini, 1987), and during precipitation events in 1987 (MoE, 1988). The Objective for suspended solids was not checked in 1988 (MoE, 1989), but was achieved on all but one sampling date at one site in 1989 (MoE, 1990).

Monitoring to determine whether Objectives for metals in water were achieved did not take place in 1986 (Rocchini, 1987), or 1988 (MoE, 1989). In 1987, the total copper Objective of 0.006 mg/L maximum was exceeded at three sites: upstream from Scott Paper, with an average of 0.006 mg/L; downstream from Scott Paper, where the maximum was 0.020 mg/L; and at Byrne Road, with a maximum of 0.020 mg/L (MoE, 1988), while it was exceeded at the Oak Street Bridge site in March 1989 (MoE, 1990).

In 1986, two of the nine chlorophenol values in water exceeded the Objective of 0.2 ug/L (Rocchini, 1987). Chlorophenol levels exceeded the Objective at three sites in 1987 as follows: at Byrne Road (0.6 ug/L on March 6th), at New Westminster (0.3 - 1.0 ug/L on March 3rd and 4th), and at the Oak Street Bridge (0.3 - 1.3 ug/L on January 7th and March 3rd) (MoE, 1988). Chlorophenol sampling results were regarded as "indefinite" in 1988 and 1989 since the sum of the individual detection limits for PCP, TTCP, and TCP was greater than the Objective level (MoE, 1989; MoE, 1990).

During 1986/87, five industrial effluent discharges were investigated on the North Arm. Two metal finishing plants occasionally had discharges which were acutely toxic to fish. At Tree Island Steel, the toxicity was considered to be primarily related to high dissolved zinc concentrations in the discharge. The cause of toxicity in the effluent from Western Canada Steel was not determined; however, increased levels of iron and aluminum were measured 100 m downstream from the discharge (Supervisory Coordinating Committee, 1987).

Treated mill wastewater effluent from Belkin Paperboard was acutely toxic to fish, with 96-h LC50 values ranging from 70-75 %. The cause of the toxicity was not determined; however, high oxygen demand and levels of mono-, di-, tri-, tetra-, and pentachlorophenol were documented in the discharge (Supervisory Coordinating Committee, 1987).

At Doman Industries (sawmill applying antisapstain chemicals), the average concentration of PCP, TTCP, and TCP at the outfall was 160 ug/L, considerably higher than the maximum Objective concentration of 0.2 ug/L which is to be measured outside the initial dilution zone. Water Quality Objectives do not apply within the initial dilution zone; however, this concentration at the outfall indicates a significant input of chlorophenols to the Fraser River (Supervisory Coordinating Committee, 1987).

2.3.2 Sediment

For sediment analyses in 1987, two sites were sampled with ten replicate grab samples taken at each, while at another five sites single grab sediment samples were taken. The particle size of the North Arm sediments was finer than those at the seven sites in the Main Stem, but coarser than the seven sites in the Main Arm. This finding is similar to that of a 1985 sediment survey. Particle size is important with respect to contaminant concentrations because smaller particles provide a larger surface area for adsorption of contaminants. Levels of contaminants in sediments between river arms generally were inversely proportional to particle size, with the exception of zinc, which was highest in North Arm sediments (Swain and Walton, 1988), associated with coarser particles. Zinc often is found at high concentrations in stormwater, and there are over 100 stormwater discharges to the North Arm.

Only one site in the three reaches had detectable levels of PCBs in sediments. This was downstream from Mitchell Island, where the recorded 0.18 ug/g (dry-weight : PCB 1254) greatly exceeded the 0.03 ug/g Objective. During a similar study in 1985, two sites on the North Arm had PCBs above the detection limit (Swain and Walton, 1988). The Water Quality Objective for PCBs in sediments was achieved in 1988 and 1989 (MoE, 1989; MoE, 1990).

TTCP was detected at four sites (0.003 ug/g wet-weight), and

PCP was detected at three sites (0.002 ug/g wet-weight) in the North Arm. When combined to total chlorophenols and a conversion factor applied to approximate dry-weight, these values are below Objectives levels (i.e., 0.010 ug/g dry-weight). These chlorophenol concentrations are an apparent decrease from 1985 levels, which, for the two sites sampled, averaged 0.050 and 0.056 ug/g wet-weight (Swain and Walton, 1988).

All concentrations of metals in sediments are reported as dry-weight in the following discussion. Barium levels appeared to decrease from 91.5 ug/g at the upstream site to 58.4 ug/g at the downstream site. This apparent trend was not related to particle size and may be due, in part, to tidal influence at the downstream site. Barium levels in 1987 were similar to those in 1985 (F-test, Student's t-test; P=0.05). Chromium levels at the upstream site decreased from 36.0 ug/g in sediments in 1985 to 29.6 ug/g in 1987, but remained similar at the downstream site between the two years. Iron values in 1987 (18 600 - 26 900 ug/g) were lower than in 1985, but higher than in 1980 (18 350 - 20 450 ug/g). Sediment manganese levels in 1987 (325.1 - 469 ug/g) were similar to those from 1985 (284 - 430 ug/g) except at MacDonald Slough, where 1987 levels were significantly lower than those in 1985. Concentrations of manganese in sediments in 1987 and 1985 were considerably higher than the levels reported in 1980 (213 - 320 ug/g). Levels of total volatile residue and total carbon were lower in 1987 than in 1985. Total inorganic carbon at MacDonald Slough was lower than in 1985. At the upstream North Arm site, phosphorus levels were also lower in 1987 (565 ug/g) than in 1985 (672 ug/g), while levels were similar at the downstream site between 1987 (667 ug/g) and 1985 (630 ug/g). In 1987, variation between upstream and downstream sites was significant (F-test; P=0.05) for sediment aluminum, barium, chromium, copper, iron, lead, nickel, manganese, mercury, vanadium, zinc, phosphorus, and total volatile residue levels. Concentrations of cobalt, copper, nickel, vanadium, and zinc were lower in 1987 than concentrations reported in 1985; however, this may be a reflection of the larger particle size of the 1987 samples (Swain and Walton, 1988).

2.3.3 Biota

Eight taxa of benthic invertebrates were sampled from two sites in each of the three reaches of the Fraser River in 1987 and analyzed for chlorophenols. Among the highest chlorophenol concentrations were those found in polychaetes from MacDonald Slough (1.0 ug/g PCP, 1.0 ug/g TTCP, 0.2 ug/g TCP, wet-weight). High levels of chlorophenols were also found in chironomids, pelecypods, leeches, and oligochaetes. This result implies considerable chlorophenol contamination in North Arm benthic biota, as would be expected from the levels of chlorophenols reported for North Arm sediments. However, while chlorophenol concentrations in benthic organisms in the Main Arm and Main Stem appear to have increased since 1985, the same does not appear to be true for the North Arm (Swain and Walton, 1988).

In 1987, sediment bioassays were conducted using the nematode, Panacirellus redivivus, and water and methanol extractions of the sediment. Significant toxic response was measured in all four samples taken from MacDonald Slough. The water extraction was more toxic than the methanol extraction in all cases (Tuominen et al., 1988).

In an August 1988 MoE/FRHC joint sampling program, fish were captured in MacDonald Slough in the North Arm. The mean PCB concentration in muscle tissue from a largescale sucker from the

North Arm was the highest value obtained (0.26 ug/g wet- weight) in muscle tissue of fish collected from the three main river reaches below Kanaka Creek. This value is about one-half the Objective for PCBs in tissue (0.5 ug/g wet-weight). Concentrations of PCBs in muscle tissue of northern squawfish from the North Arm were considerably lower than the same species in the Main Arm or Main Stem. The highest PCB levels in livers of fish for most species, generally occurred in North Arm. One exception was in starry flounder from the Main Arm which had higher levels than measured elsewhere. While PCBs were measurable in tissue of fish from the North Arm, it appears that levels were lower in 1988 than in 1980 or 1972/73 (Swain and Walton, 1989).

Phthalate esters were detected in muscle and liver tissue of North Arm fish sampled in 1988. Of the six phthalate esters sampled, dimethyl phthalate was detected only in muscle tissue of North Arm fish. Diethyl phthalate and di-n-octyl phthalate were detected in the fish livers only in the North Arm, although it was present in most muscle tissue analyzed from all three reaches of the Fraser River. While sufficient data were not available for anything but a tentative conclusion, it appears that di-n-butyl, butyl benzyl, and bis (2-ethylhexyl) phthalate may be accumulating in fish livers (Swain and Walton, 1989).

PAHs were detected in fish muscle tissue only in the North Arm, PAHs in fish livers were more widespread. Of the sixteen PAHs monitored, only three were detected in muscle tissue: acenaphthene in threespine stickleback (0.007 and 0.008 ug/g wet-weight); fluoranthene in starry flounder (0.01 ug/g) and in threespine stickleback (0.01 and 0.011 ug/g); and phenanthrene in peamouth chub (0.02 ug/g), starry flounder (0.02 ug/g), and threespine stickleback (0.019 and 0.026 ug/g). PAHs were detected more often in liver than in muscle tissue. The most common PAHs found in livers were fluorene, naphthalene, and phenanthrene. Generally, there were no statistical differences (F-test; Student's t-test, P=0.05) between PAHs in fish liver in samples from the Main and North arms, or within species in each Arm (Swain and Walton, 1989).

Seven of sixteen organochlorine pesticides (OCs) monitored were commonly found in fish muscle in 1988. Of the other nine OCs measured, endrin, heptachlor epoxide, and lindane were found only in North Arm fish. Eight organochlorine pesticides were found in fish livers, with DDD and DDE being the most common. The highest DDE concentrations in fish livers were for peamouth chub and northern squawfish from the North Arm (160 ng/g wet-weight). Mean DDE values for muscle and liver for the same fish species generally were not different between sites. The exception was muscle tissue of northern squawfish from the North Arm (mean of 8.1 ng/g wet-weight), which was higher than those from the Main Arm (mean of 3.74 ng/g wet-weight) (Swain and Walton, 1989).

Arsenic levels in North Arm fish were generally higher than for fish from the Main Arm or Main Stem. The highest arsenic concentrations in fish muscle tissue were found in staghorn sculpin (0.31 ug/g) in the North Arm compared to 0.24 ug/g (wet-weight) in the Main Arm) and in starry flounder (0.57 ug/g) in the North Arm when compared to 0.40 ug/g (wet-weight) in the Main Arm. Arsenic was detected in some fish muscle tissues in a 1980 study when the detection limit was 0.4 ug/g (wet-weight). In 1988 with a detection limit of 0.025 ug/g, only one sample from the North Arm exceeded the 1980 detection limit. The highest arsenic concentration found in fish liver was that of starry flounder from the North Arm (0.45 ug/g, wet-weight) (Swain and Walton, 1989).

Chromium values within species were highest in fish muscle tissue from the North Arm. Starry flounder had the highest muscle chromium concentration, with a mean of 2.05 ug/g (wet-weight). North Arm fish livers were not the highest among river reaches regarding chromium contamination. Copper concentrations in fish muscle tissue varied among species in each Arm. Mean copper levels in muscle of peamouth chub (0.39 ug/g), staghorn sculpin (0.50 ug/g), and starry flounder (0.94 ug/g wet-weight), were highest in the North Arm among river reaches. Mean copper levels in liver (3.06 - 6.61 ug/g wet-weight) were similar to those from fish from the Main Arm and Main Stem. Manganese values in muscle tissue of starry flounder (4.82 ug/g wet-weight) and threespine stickleback (7.59 ug/g wet-weight) were considerably higher than in fish from "uncontaminated" lakes (0.148 to 1.50 ug/g wet-weight). Manganese concentrations in livers of fish from the North Arm were similar to levels in the livers of fish from uncontaminated lakes (Swain and Walton, 1989).

Nickel was not detected in muscle or liver tissue (< 0.02 ug/g wet-weight)in a 1980 study. However, in 1988, two nickel values exceeded the 1980 detection limit. Mean nickel values for muscle tissue of peamouth chub (0.26 ug/g wet-weight) and staghorn sculpin (0.46 ug/g wet-weight) from the North Arm were significantly higher (F-Test, Student's "t" test; P=0.05) than for the same species from the Main Arm or Main Stem, higher than other species in the North Arm. Mean nickel values were about twice as high as for fish from uncontaminated lakes. Nickel concentrations in fish livers were higher in peamouth chub from the North Arm (0.24 ug/g wet-weight) than those from the Main Arm (0.06 ug/g wet-weight) or the Main Stem (0.12 ug/g wet-weight). Nickel concentrations appeared higher in liver than muscle of largescale suckers, while northern squawfish and peamouth chub muscle and liver concentrations appeared to be similar (Swain and Walton, 1989).

In the North Arm, zinc levels in fish tissue did not seem to have changed compared to earlier studies. High maximum values of zinc in tissue were recorded for starry flounder (17.9 ug/g wet-weight) and threespine stickleback (33.5 ug/g wet-weight). These maximum values are about five times greater than those from fish from uncontaminated lakes. In both the 1980 and 1988 surveys in the North Arm, it was found that zinc concentrations in fish livers were about five times that of fish muscle. The highest level of zinc in fish liver was found in North Arm staghorn sculpin (70.1 ug/g wet-weight) compared to that of staghorn sculpin (63.9 ug/g wet-weight) from the Main Arm, and peamouth chub from the Main Stem (18.1 ug/g wet-weight). The concentration of zinc in the liver of staghorn sculpin from the North Arm was about twice the level found in fish from uncontaminated lakes (Swain and Walton, 1989).

2.3.4 Conclusions

More frequent monitoring is required to adequately assess compliance with the Water Quality Objectives for most characteristics. However, based on limited data available, fecal coliform and dissolved oxygen levels in the North Arm have improved, and levels of copper in water appear to have increased in the North Arm relative to previous data records.

Concentrations of chlorophenols in sediments remain elevated but there is an indication that they have decreased from previous 1985 levels. Phosphorus and chromium concentrations in sediments have decreased at upstream sites; however, levels of manganese appear to have increased in the North Arm since 1980.

Considerable chlorophenol contamination was noted in benthic organisms in 1988. Concentrations have not changed from levels reported in earlier studies. It is expected that these levels will decrease in the future with the elimination of chlorophenates as wood protection chemicals; however, this may only result in the focus for concern changing from chlorophenols to the new replacement chemicals.

In general, fish from the North Arm had higher concentrations of contaminants in tissues than fish from the Main Arm or Main Stem. While levels were detectable, PCB, organochlorine pesticide, and arsenic concentrations in fish tissue appear to have decreased from previous levels. Phthalate esters appear to be accumulating in liver tissue. Nickel concentrations in both muscle and liver tissue of fish increased from previous sampling data.

2.4 STURGEON AND ROBERTS BANKS

2.4.1 Water

The only Water Quality Objectives monitoring carried out on the Banks for the water column was in 1987 and 1988 for fecal coliforms. The fecal coliform Objective (200/100 mL geometric mean, June - August) was met at all sites sampled at Iona and Tsawwassen Beaches (MoE, 1988 and 1989).

2.4.2 Sediment

In 1986, the only Objective monitoring on Sturgeon Bank was chlorophenol in sediments. Of the ten analyses of sediment cores, five were 5 or more times greater than the Objective, four were close to the 10 ug/g (dry-weight) maximum, and one was not detected

(Rocchini, 1987).

The Objective for chlorophenols in sediments from Sturgeon and Roberts Banks was checked in 1988. The Objective for chlorophenols in sediments of 0.01 ug/g maximum (dry-weight) was met at four sites on Sturgeon Bank and two sites on Roberts Bank (MoE, 1989).

In February 1988, Colodey (1989) (Environment Canada) reported on sediment from eleven stations on Sturgeon and Roberts Banks. Chlorophenols (PCP and 2,3,6 - TCP) were highest at Musqueam Marsh and near the former Iona outfall surface discharge site (1.3 and 0.9 ng/g dry-weight). PCB (Arochlor - 1248) was detected (0.02 ug/g dry-weight) in Sturgeon Bank Marsh and Woodward Island sediments. Lead levels were elevated on Sturgeon Bank.

The Apparent Effects Threshold (AET) has been determined for Puget Sound. The AET is the concentration of a characteristic that has been noted to have some effect on an organism (Tetra Tech, 1986). Iron was above benthic AET levels at two sites on Sturgeon Bank (Colodey, 1989). Nickel and cadmium were both elevated above benthic AET levels at the boundary of Sturgeon and Roberts banks.

Moody (1989) sampled sediments at four sites across the estuary in September 1987, February 1988, and July 1988. The highest single cadmium level in sediments was from Musqueam Marsh (0.43 ug/g), although the Woodward Island site usually had the highest levels of cadmium in sediments (0.27 - 0.43 ug/g). Lead levels in Musqueam Marsh sediments (39.9 ug/g) were almost twice that at the other sites in the estuary. Woodward Island sediments exhibited the lowest lead levels measured. Mercury levels in sediments were highly variable among sites, but levels at Woodward Island generally were lowest. The highest levels of organic contaminants in sediments generally were found at Musqueam Marsh (0.01 ug/g) except for a high TCP result from the Richmond foreshore (0.04 ug/g). However, the lowest PCB levels were found at the Richmond foreshore site (Moody, 1989).

Moody (1989) also investigated the uptake of contaminants in plants in the Fraser Estuary. Cadmium was found in vegetation at concentrations up to four times the sediment levels, mercury was to up 1.9 times higher, and PCBs were up to 11.9 times higher in vegetation than in sediment. The highest concentrations of chemicals were noted in the plant roots in the fall and is probably reflective of the accumulation of contaminants by plants during a growing season, and would apply to many areas, not just the Fraser River Estuary. No trends were evident between contaminant concentration in vegetation and the related sediment or water concentrations (Moody, 1989).

2.4.3 Conclusions

Fecal coliform concentrations for Sturgeon and Roberts banks were at concentrations such that the Water Quality Objectives were achieved in 1987 and 1988.

Sediments contained measurable concentrations of chlorophenols, and significant levels of nickel, cadmium, iron, and lead. The most recent data for chlorophenol concentrations in sediments indicate that the Water Quality Objective for chlorophenols in sediments was achieved on Sturgeon and Roberts banks.

Intertidal vegetation may be accumulating some heavy metals, likely from sediments.

2.5 BOUNDARY BAY AND ITS TRIBUTARIES

2.5.1 Water

Due to the large number of Water Quality Objectives in this area, the focus of the discussion will be those characteristics where the Objectives were not achieved. This is done to shorten the discussion. Objectives were monitored in 1988 and 1989 for eleven different characteristics.

The Boundary Health Unit has monitored recreational water quality at Boundary Bay beaches since 1960. In 1988, thirteen sites were sampled every week for fecal coliform contamination, and a running geometric mean was calculated. Of all geometric means calculated, 714 were below 50 fecal coliforms /100 mL, 964 were below 100 fecal coliforms /100 mL, and 1 004 were below 160 fecal coliforms /100mL. The Objective is a geometric mean of < 200/100mL for primary-contact recreation, from April to October (Swain and Holms, 1988). Two individual samples exceeded the Objective of 400/100mL as a 90th percentile. These excursions were at White Rock (550/100 mL) and at Boundary Bay Beach (500/100 mL) (MoE, 1989).

Fecal coliform concentrations in 1989 were elevated and the Water Quality Objectives were not met at near Centennial Beach (10 to 3500/100 mL) or White Rock (85 to 3950/100 mL) in the early August period (MoE, 1990). The Objectives on occasion were also exceeded during other time periods at other sites.

Beaches were temporarily closed in White Rock and Crescent Beach in August 1988 in response to the rupture of Blaine's trans-harbour sewage line (Standing Committee, 1989). This action was taken not as a result of sampling data for the area but due to the high potential health risk (Standing Committee, 1989).

From 1986 to 1987, Higgs and Associates sampled 33 marine and 5 freshwater stations in the Boundary Bay area for fecal coliforms. The sites sampled included 10 ambient marine stations, 5 stormwater pump station discharges, 3 tidal channels, and 2 freshwater streams. Among the conclusions were: pump stations are a major source of coliforms to the Bay; marine sites adjacent to pump stations showed high levels of fecal coliforms during high rainfall events; ambient fecal coliform levels decreased rapidly with the onset of dry weather conditions; and intertidal areas on the south side of Boundary Bay appeared to have water quality suitable for commercial oyster production (Higgs 1989).

In the Little Campbell River, Water Quality Objectives in 1988 and 1989 for suspended solids, turbidity, and nitrite were frequently not met near the mouth. Dissolved oxygen levels were frequently low (2.1 - 4.8 mg/L) and did not achieve the Objective level near its headwaters (MoE, 1989; MoE, 1990).

In the Nicomekl River, the Water Quality Objectives for suspended solids, turbidity, and dissolved oxygen were occasionally not met near the mouth in 1988 or 1989, while the same was the case for pH Objectives in 1988 (MoE, 1989; MoE, 1990). Objectives for nitrite were exceeded at both sites each year.

In Anderson Creek, a tributary to the Nicomekl River, nitrite Objectives were exceeded near the source in 1988 but were achieved in 1989 (MoE, 1989; MoE, 1990). Dissolved oxygen concentrations were usually above the Water Quality Objective which varies according to season. The higher Objective of 11.0 mg/L was not achieved in November 1989 near the headwaters when values were in the range from 10.0 to 10.4 mg/L (MoE, 1990).

In Murray Creek, another Nicomekl River tributary, nitrite and the maximum fecal coliform Objectives were exceeded near its source in 1988, although not in 1989 (MoE, 1989; MoE, 1990). Turbidity Objectives were exceeded occasionally near the mouth of Murray Creek in 1988 and 1989 (MoE, 1989; MoE, 1990). Concentrations of suspended solids and substrate sedimentation in Murray Creek, which in 1988 had been at concentrations where the Objective was achieved, on occasion in 1989 did not achieve the Water Quality Objective (MoE, 1990). Dissolved oxygen concentrations in Murray Creek were such that the Water Quality Objective was not achieved on one date in November 1989 at both sites (10.8 and 10.9 mg/L) (MoE, 1990).

In the Serpentine River, pH and suspended solids during 1989 and turbidity and dissolved oxygen Objectives in 1988 and 1989 were exceeded near the mouth, while pH in 1988 and nitrite Objectives in 1988 and 1989 were not met at the mouth or at the upstream site (MoE, 1989; MoE, 1990). The Water Quality Objective for dissolved oxygen was not achieved near the headwaters of the Serpentine River in 1989 when the range of concentrations was from 1.4 to 5.7 mg/L in October and 5.8 to 7.2 mg/L in November (MoE, 1990).

For tributaries of the Serpentine River in 1988 and 1989, the fecal coliform Objective was exceeded near the mouths of Mahood and Latimer creeks; while in Hyland Creek, fecal coliforms did not meet Water Quality Objectives at the two sites sampled (MoE, 1989; MoE, 1990). Suspended solids were above the Water Quality Objective levels near the mouths of all three tributaries in 1988 and 1989, while turbidity exceeded the Water Quality Objective in Mahood and Hyland creeks in 1988 and 1989 and Latimer Creek in 1988 (MoE, 1989;

MoE, 1990).

2.5.2 Sediment

In 1989, sediment sampling was carried out at ten sites in Boundary Bay (9 intertidal and 1 subtidal) in a joint MoE/FRHC study. In addition, sediment samples were taken from five drainage ditches upstream from the stormwater pump stations, upstream from the tidal gates on the Serpentine and Nicomekl rivers, and upstream from the tidal influence on the Campbell River.

PCBs in marine sediments were detected once, at the offshore site (0.017 ug/g dry-weight) (Swain and Walton, 1990). Two other sites sampled for sediments in Boundary Bay's subtidal zone in 1988 had PCBs below the 0.02 ug/g dry-weight detection limit (MoE 1989). PCBs were found upstream from the stormwater pump stations at Beach Grove (0.034 ug/g dry-weight) and west from the Delta airfield (0.011 ug/g dry-weight) in 1989 (Swain and Walton, 1990). In sediments from the three rivers (Serpentine, Nicomekl, and Little Campbell), only the site on the Nicomekl River (0.024 ug/g) had PCBs above the detection limit (Swain and Walton, 1990).

Chlorophenols were not detected at any marine stations and were found in only one sediment sample from upstream from the stormwater pump station east from Grauer Point (0.005 ug/g dry-weight) (Swain and Walton, 1990).

Of the six phthalate esters monitored in sediments, five were detected, as follows. Bis (2-ethylhexyl) phthalate was detected at all sites except upstream from the stormwater pump station east of Grauer Point. For three phthalates, the highest concentrations were found at the offshore station: bis (2-ethylhexyl) phthalate was detected in all five replicates at concentrations from 0.68 - 1.48 ug/g (dry-weight); di-n-butyl phthalate at concentrations of 0.16 and 0.29 ug/g (dry-weight); and diethyl phthalate was detected at 0.29 ug/g (dry-weight). Di-n-octyl phthalate was highest at the marine station east from Blackie Spit (0.31 ug/g dry-weight), and butyl benzyl phthalate was highest at the inshore site (0.16 ug/g dry-weight) (Swain and Walton, 1990). These data have not been adjusted for background contamination levels of phthalates, which are routinely detected in the environment. By comparison, sediments near the Iona STP in 1983 had bis (2-ethylhexyl) phthalate at 170 ng/g (dry-weight) and di-n-butyl phthalate at 446 ng/g (dry-weight) (Rogers and Hall, 1987).

Organochlorine pesticides (OCs) were common generally in marine sediments sampled and upstream from the stormwater pump stations. OCs were present in sediments from the three tributaries to Boundary Bay. The greatest number of OCs were found in sediments collected adjacent to the pump stations at Beach Grove and west and east from the Delta airfield. The most common OCs in the ditch sediments were DDE at four sites (up to 0.005 ug/g, dry-weight), endosulfan I at four sites (up to 0.002 ug/g, dry-weight), and endosulfan II at five sites (up to 0.002 ug/g, dry-weight). At the marine stations, the most common OCs were heptachlor at three sites with concentrations from (0.007 to 0.016 ug/g, dry-weight), and heptachlor epoxide at two sites (0.012 and 0.014 ug/g, dry-weight). In general, the largest number of OCs detected and the highest concentrations found at the marine sites was at the subtidal station. The OCs were not detected at the two marine sites, at Beach Grove, or the Little Campbell River Estuary (Swain and Walton, 1990).

All PAHs tested for in sediments from Boundary Bay and its tributaries were detected. Benzo(a)pyrene was only detected at the marine subtidal site. The highest number of PAHs was detected at the subtidal site, although concentrations were frequently higher at the other sites. Acenaphthylene (0.62 ug/g dry-weight) in sediments from the site east of Grauer Point exceeded the AET for amphipods (Tetra Tech, 1986). At the site north from the mouth of the Serpentine River, all five sediment samples contained dibenzo (a,h) anthracene at levels (0.63 - 1.24 ug/g dry-weight) at least twice as high as the AET for Microtox and oysters (0.23 ug/g dry-weight). Sediments from upstream from the four stormwater pump stations and the three Boundary Bay tributaries, were at levels well below the AET levels. Sediment collected upstream from the stormwater pump station at Beach Grove exhibited concentrations of two PAHs approaching AET levels (Swain and Walton, 1990).

Levels of metals in Boundary Bay sediments were generally lower than levels in the Fraser River. An exception was at the subtidal sampling site. Chromium levels (50.2 - 59.1 ug/g dry-weight) and iron levels (30 900 - 33 300 ug/g dry-weight) were higher at the subtidal sampling site than at Fraser River sites. Two cadmium values (0.62 and 1.12 ug/g dry-weight) exceeded the 0.6 ug/g dry-weight limit for sediments under the Ocean Dumping Control Regulation. Some metals levels in sediments adjacent to the pump stations were high, notably lead (41.5 - 81.8 ug/g dry-weight), cadmium (1.05 - 1.45 ug/g dry-weight), copper (72.7 ug/g dry-weight) and zinc (173 ug/g dry-weight). The highest sediment metal values for the pump stations were found at Beach Grove. Lead levels were elevated in the Serpentine River sediments (42.1 ug/g dry-weight) (Swain and Walton, 1990).

2.5.3 Biota

Two sites (one intertidal and a second subtidal) were sampled in Boundary Bay for fish and crab during the 1989 study. Clams were collected from two sites adjacent to two stormwater pump stations.

Arsenic, chromium, lead, and mercury concentrations in crab flesh were low in comparison to concentrations in crabs from Burrard Inlet (Swain and Walton, 1990). The lead concentrations in the crabs from Burrard Inlet seemed to be influenced by the season of the year, with higher concentrations occurring when stormwater runoff was taking place (Swain and Walton, 1990). Arsenic and zinc concentrations in some fish species were higher in Boundary Bay fish tissue than found in the same species from the Fraser River Estuary or Burrard Inlet, although the converse was true for chromium, lead, and mercury (Swain and Walton, 1990).

Crabs and fish collected from Boundary Bay had higher cadmium and copper concentrations than crabs and the same species of fish from Burrard Inlet or the Fraser River Estuary (Swain and Walton, 1990). Cadmium has been used in pesticide formulations, primarily for golf course greens, as well as in some fertilizers, while copper is used in general purpose pesticides and fertilizers (Swain and Walton, 1990).

Data for PAHs, OCs, phthalate esters, chlorophenols, and PCBs in biota had not been reviewed at the time of publication of this report.

2.5.4 Conclusions

Fecal coliform levels in Boundary Bay met Water Quality Objectives in 1988 but not all the time in 1989. Tributaries to Boundary Bay, including drainage ditches, introduced significant levels of fecal coliforms to the Bay. On the Serpentine, Nicomekl;

and Little Campbell rivers and their tributaries, few Water Quality Objectives were consistently met.

There is considerable contamination of sediments in the drainage ditches emptying into Boundary Bay. These contaminants, including PCBs, phthalate esters, organochlorine pesticides, PAHs, chromium, iron, and cadmium appear to be accumulating in the subtidal sediments in Boundary Bay.

Cadmium and copper were higher in biota from Boundary Bay than in similar species from Burrard Inlet or the Fraser River.

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GLOSSARY OF TERMS

Absorption	The incorporation of a substance into the body of another (cf. sorption).
Acute toxicity	A pronounced effect (severe biological harm or death) produced in an organism by a substance or mixture of substances within a short period of time (usually 96 hours or less) after exposure.
Adsorption	The attachment of a substance on the surface of another (cf. sorption).
Aerobic	Denotes the presence of gaseous or dissolved oxygen (cf. anaerobic).
Algae	A group of simple chlorophyll-containing lower plants, mostly aquatic;although most are microscopic , some forms reach extremely large size.
Algal bloom	A bloom of algae occurs when their growth is so rapid that they become numerous enough to colour a body of water.
Amphipoda	Order of Crustacea, including freshwater shrimp.
Ambient	Refers to conditions in the surrounding environment.
Anadromous	Ascending from the sea to freshwater for spawning at certain seasons.
Anaerobe	An organism that can only exist in the absence or near-absence of gaseous or dissolved oxygen.
Anaerobic	Denotes the absence of gaseous or dissolved oxygen.
Anion	A negatively charged ion.
Anthropogenic	Relates to, or involves, the impact of man.
Aromatic compound	A general term that includes the "hydrocarbons" of the benzene series.
Benthic organism (Benthos)	Any organism that lives in or near the bottom of a water body or in the sediment thereof.

Bioaccumulation	The uptake, retention, and concentration above background levels of environmental substances by an organism from its environment.
Bioassay	Quantitative estimation of biologically active substances by the amount of their actions in standardized conditions on living organisms.
Biomagnification	The increase of a substance (contaminant) in a food web such that the organisms eventually contain higher concentrations of the substance than their food sources (cf. bioaccumulation).
Biota	Living organisms including bacteria, plants, and animals.
Buffer	A compound or solution capable of resisting a change in pH.
Carcinogen	A substance capable of causing cancer.
Cation	A positively charged ion.
Chlorophenols	Broad spectrum pesticides produced when phenol rings have a number of chlorine atoms attached. Used in wood processing to prevent discolouration by fungus.
Chlorophyll-a	Green pigment found in all plants except fungi and a few flowering plants which is essential for photosynthesis.
Chronic toxicity	A long-term toxic effect produced in an organism by a substance or mixture of substances (e.g. toxin).
Combined sewer overflow	A point in a sewer collection system where domestic sewage mixed in varying proportions with stormwater overflows to a receiving water body.
Contaminant	A substance that infects by contact or association.
Copepoda	Subclass of Crustacea; small aquatic invertebrates that are food for fish.
Designated water use	A water use that is to be protected at a specific location.

Diffuser	A structure composed of several components, placed at the end of an outfall pipe, which is designed to spread the effluent widely so as to improve dilution.
Disinfection	The process of destroying microorganisms in water by the application of a chemical agent (disinfectant) such as chlorine.
Dissolved metals	in solution in a liquid; metals which pass through a filter are assumed for environmental purposes to be dissolved.
Estuary	The lower end of a river where the tide meets a river current.
Eutrophication	The process of increasing the nutrient content of natural waters, so that biomass productivity is increased.
Food chain	The transfer of food energy from producers through a series of consumers.
Food web	A series of inter-connecting food chains.
Fraser River Estuary	The area of joint social, economic and environmental concerns for the purposes of the FREMP Agreement, means in general, the land and water outside boundary of the dykes and between Kanaka Creek and the outlet from Pitt Lake in the east, the estuary drop off in the west, Point Grey to the north, and the international boundary to the south, including Boundary Bay and Semiahmoo Bay.
Geometric mean	The nth root of the product on "n" observations.
Habitat	A place with a particular kind of environment inhabited by organisms.
Heavy metals	Metallic elements of high molecular weight (e.g., copper, lead, etc.) typically with specific gravities greater than 5.
Hepatic	Adjective. Of the liver.

Initial dilution zone	Areas adjacent to a wastewater discharge wherein Water Quality Objectives (except those in fish) do not apply.
Invertebrate	Organism without a backbone.
Larvae	The pre-adult form in which some animals hatch from the egg.
Metalloid	Resembling a metal, or having chemical properties similar to metals.
Methylation	The process whereby a compound is modified chemically (often through bacterial action) by the replacement of a hydrogen atom by a methyl group (CH_3).
Micrograms per litre (ug/L)	One one-thousandth of one milligram per litre.
Milligrams per litre (mg/L)	A concentration unit of chemical constituents in solution; the weight of solute (substance) per unit volume of solvent (water).
Mollusca	Major group of mostly aquatic animals which are soft bodied, often with a hard shell (e.g., clams, bivalves, snails, octopus, squid).
Most Probable Number (MPN)	The statistically determined number that represents the number of individual bacteria most likely to be present in a given sample.
Muscle	Tissue consisting of cells which are highly contractile. Most of edible parts of animals (flesh) is muscle.
Nutrient	Substance (element or compound) necessary for the growth and development of plants and animals.
Oligochaetes	Freshwater worms. cf. polychaetes.
Organic contaminant	Organic chemicals which commonly are toxic, persistent, and mobile in the environment.
Pathogenic	Giving origin to, or resulting in, disease or death (pathogenic organisms and pathogens).

Pelecypoda	Bivalves, class of aquatic molluscs with bivalve shells.
pH	Negative of the logarithm (base 10) of the hydrogen ion concentration. Quantitative expression for acidity or alkalinity of solution. Scale ranges from 0 to 14, pH 7 is neutral; less than 7 is acid; more than 7 is alkaline.
Photosynthesis	The process by which the chlorophyll-bearing cells of green plants, in the presence of light, convert carbon dioxide and water into sugar (an organic compound) with the evolution of oxygen.
Phytoplankton	The plant portion (phyto-) of the free-water community (plankton).
Plume	A portion of a water body which is indistinguishable from the remainder because it is not completely mixed and its characteristics are measurably different.
Polychaetes	Marine worms. Cf. oligochaetes.
Polychlorinated biphenyl (PCB)	Scientific name for man-made liquid chemicals that are stable, non-corroding, fire resistant, and relatively non-biodegradable. Once used in electrical transformers because of these properties.
Primary sewage treatment	Removal of settleable solids through filtering, screening, and/or settling.
Pristine	Describes a natural system (e.g., water) that has not been affected by anthropogenic pollution.
Saline	Waters having salt concentrations approaching that of seawater.
Salmonid	Fish of the family Salmonidae; including trout, salmon, and char.
Secondary sewage treatment	Includes primary treatment and provides conditions for the biological oxidation of organic wastes.
Sidechannel	A slow moving body of water usually with two ends open to the main water body.

Slough	A slow moving body of water usually with an end open to the main water body.
Sorption	A general term for the process of absorption and adsorption. It is often used to denote the occurrence of both.
Spatial	Of or relating to space.
Sublethal	Involves an effect below the level that causes death.
Synergism	Combined activity such that the effect is either the additive of separate effects or greater than the sum of the separate effects.
Temporal	Of, or relating to time.
Tertiary Sewage Treatment	A third step in sewage treatment usually directed at greatly increasing the removal efficiency of nutrients.
Total Metal	A measure of metals in the dissolved state and those sorbed to particulate matter in suspension.
Toxic	Pertaining to, due to, or of the nature of, a poison, thus toxicity; the quality of being poisonous.
Water Quality Criteria	Numerical value(s) for a physical, chemical, or biological characteristic of water, biota, or sediment which must not be exceeded to prevent specified detrimental effects from occurring to water use.
Water Quality Guideline	Numerical concentration or narrative statement recommended to support and maintain a designated water use.
Water Quality Objective	A Water Quality Criterion or Guideline adapted to protect the most sensitive designated water use at a specific location with an adequate degree of safety, taking local circumstances into account.

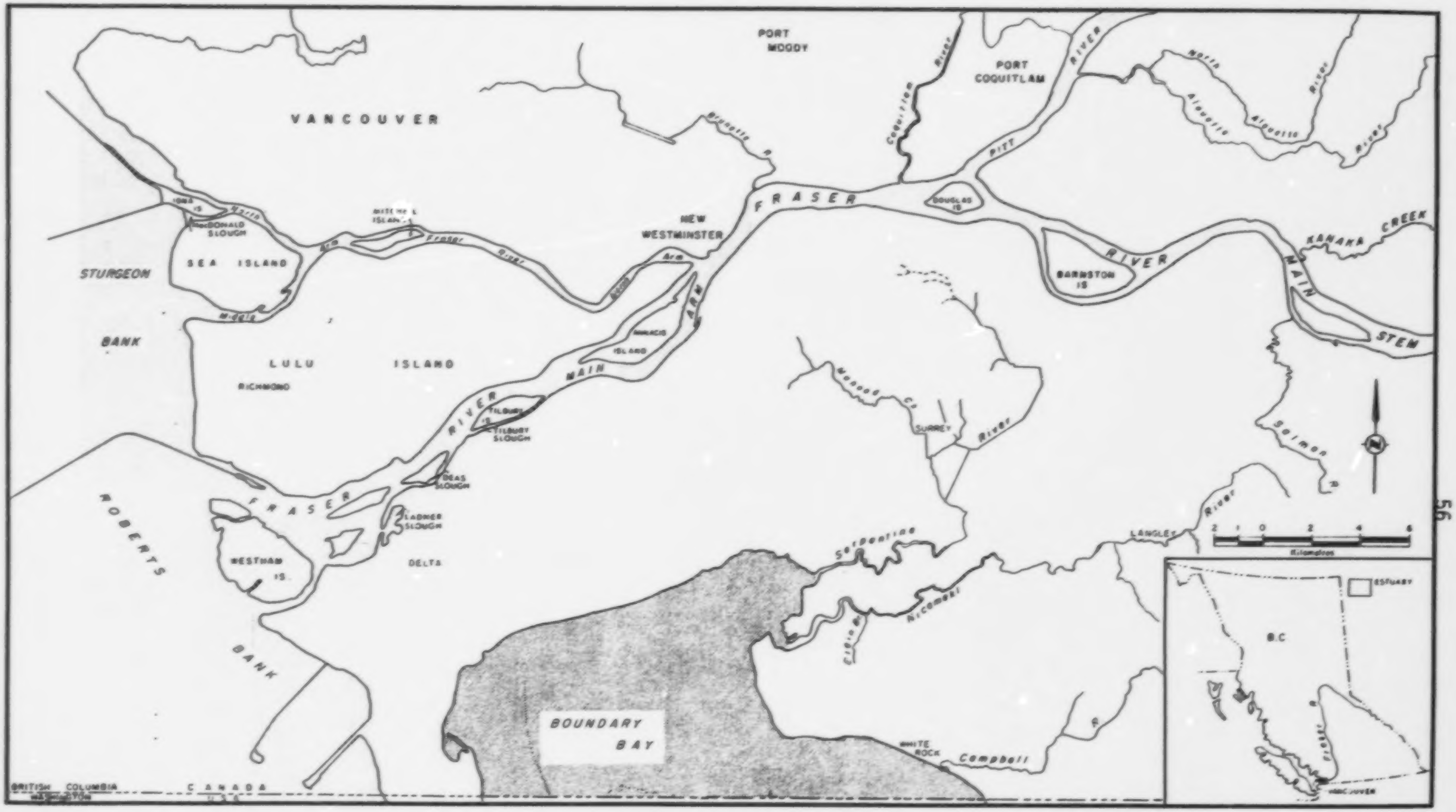

FIGURE 1 : THE FRASER RIVER ESTUARY

TABLE 1
PROVISIONAL WATER QUALITY OBJECTIVES FOR THE FRASER RIVER SUB-BASIN FROM KANAKA CREEK TO THE MOUTH

(Prepared and Issued by B.C. Ministry of Environment)

WATER BODIES	FRASER RIVER			STURGEON AND ROBERTS BANKS
	MAIN STEM	NORTH AND MIDDLE ARMS	MAIN ARM	
Designated Water Uses	Aquatic life, wildlife, recreation, livestock, irrigation			Aquatic life, wildlife, recreation
Fecal Coliforms[1]	≤1 000 MPN/100 mL geometric mean April - October 4 000 MPN/100 mL maximum April - October			≤200 MPN/100 mL geometric mean and ≤400 MPN/100 mL 90th percentile, at bathing beaches from June through August
Suspended Solids[2]	not applicable	10 mg/L maximum increase (upstream ≤100 mg/L) 10% maximum increase (upstream ≥100 mg/L)	not applicable	
Total Chlorine Residual[3]	not applicable		0.002 mg/L maximum	
Un-ionized Ammonia -N [4]	not applicable	0.03 mg/L maximum, ≤0.007 mg/L average		
Dissolved Oxygen	7.75 mg/L minimum			9 mg/L minimum
pH [5]	6.5 - 8.5			not applicable
Total Copper[4]	not applicable	For hardness ≥ 35 mg/L: 0.006 mg/L maximum, ≤0.004 mg/L average or 20% maximum increase, whichever is greater For hardness < 35 mg/L: 0.004 mg/L maximum, ≤0.003 mg/L average or 20% maximum increase, whichever is greater		not applicable
Total Lead[4]	not applicable	0.010 mg/L maximum ≤0.003 mg/L average		not applicable
Total Zinc [4]	not applicable	≤0.05 mg/L average 0.10 mg/L maximum		not applicable
Chlorophenols[6],[7],[8]	10 ppb (dry weight) maximum in bottom surface sediments 0.1 ppm (wet weight) maximum in fish muscle 0.2 µg/L maximum in water			10 ppb (dry weight) maximum in bottom surface sediments
PCB's [7],[8],[9]	30 ppb (dry weight) maximum in bottom surface sediments 0.5 ppm (wet weight) maximum in fish muscle			not applicable

TABLE 1 - CONT'D
PROVISIONAL WATER QUALITY OBJECTIVES

Note: The objectives apply to discrete samples from all parts of the waterbodies, except from initial dilution zones of effluents. These excluded initial dilution zones in the Fraser River are defined as extending up to 100 m downstream (or upstream at times of tide reversal) from a discharge, and occupying no more than 25% of the stream width around the discharge point, from the bed of the stream to the surface. These excluded initial dilution zones in marine waters are defined as extending up to 100 m horizontally in all directions, but not to exceed 25% of the width of the waterbody. This exclusion does not apply to objectives for fish as noted in 8 below.

[1] The geometric mean and the 90th percentile are calculated from at least five weekly samples taken in a period of 30 days. The recreation objective (200-400/100 mL) applies during the recreation season and the irrigation objective (1 000 - 4 000/100mL) applies during the irrigation season.

[2] The increase (in mg/L, or %) is over levels measured at a site upstream from a discharge or series of discharges and as close to them as possible, and applies to downstream levels.

[3] Since the objective is less than the minimum detectable concentration, it will be necessary to estimate the receiving water concentration using effluent load and stream flow. The objective applies only if sewage effluent is chlorinated.

[4] The average is calculated from at least five weekly samples taken in a period of 30 days.

[5] Measurements can be made in-situ, but must be confirmed in the laboratory if the objective is exceeded.

[6] The term chlorophenol means the sum of tri-, tetra-, and pentachlorophenol which may be present in water, sediment or fish.

[7] The maximum value should not be exceeded in bottom surface sediments taken in any part of the sub-basin, except in the initial dilution zones of effluents. The average of at least three replicate sediment samples taken from the same site should be used to check the objective.

[8] The objective applies only to fish muscle tissue, not the whole fish or organs, of a fish of any species caught in any part of the sub-basin, including the initial dilution zones of effluents.

[9] The term PCB's applies to the sum of a Aroclor 1242, 1254, and 1260, which may be present in water, sediment or fish.

Source: Swain and Holms 1985

TABLE 2
PROVISIONAL WATER QUALITY OBJECTIVES FOR THE LITTLE CAMPBELL RIVER, NICOMEKL RIVER, SERPENTINE RIVER, THEIR TRIBUTARIES, AND BOUNDARY BAY

(Prepared and Issued by B.C. Ministry of Environment)

Water Bodies	Little Campbell River and tributaries	Mahood, Hyland and Latimer Creeks	Serpentine River	Nicomekl River	Anderson and Murray Creeks	Boundary Bay
Designated Water Uses / Characteristics	Aquatic life, wildlife, irrigation, livestock watering, primary-contact recreation	Aquatic life, wildlife, irrigation, livestock watering	Aquatic life, wildlife, irrigation, livestock watering	Aquatic life, wildlife, irrigation, livestock watering	Aquatic life, wildlife, irrigation, livestock watering	Aquatic life, wildlife, primary-contact recreation
Fecal Coliforms[1]	≤200 MPN/100 mL geometric mean (April to October) ≤400 MPN/100 mL 90th percentile (April to October)	≤1000 MPN/100 mL geometric mean (April-October) ≤4000 MPN/100 mL maximum (April-October)				≤200 MPN/100 mL geometric mean (April to October) ≤400 MPN/100 mL 90th percentile (April to October)
	not applicable	≤200 MPN/100 mL geometric mean (year-round) (long-term objective)				≤14 MPN/100 mL median (year-round) (long-term objective) ≤43 MPN/100 mL 90th percentile (year-round) (long-term objective)
Suspended Solids[2]	10 mg/L maximum increase (upstream ≤100 mg/L) 10% maximum increase (upstream >100 mg/L)					
Substrate Sedimentation[2]	No significant increase (95% confidence level) by weight in particulate matter for particles <3 mm in diameter					
Turbidity[2]	5 NTU maximum increase (upstream ≤50 NTU) 10% maximum increase (upstream >50 NTU)					
Total Ammonia-N	See Tables 3 and 4					not applicable
Nitrite-N	See Table 5					not applicable
Periphyton Chlorophyll-*a*[3]	50 mg/m^2 maximum average	100 mg/m^2 maximum average: long-term objective		100 mg/m^2 maximum average		not applicable
Dissolved Oxygen	6.0 mg/L minimum (June-October)	8.0 mg/L minimum	6.0 mg/L minimum (June-October)		8.0 mg/L minimum	6.5 mg/L minimum 9.0 mg/L minimum (long-term objective)
	11.0 mg/L minimum (when fish salmonid eggs and larvae or alevin are present)					
	8.0 mg/L long-term objective for minimum (June-October)	not applicable	8.0 mg/L minimum (June-October) (long-term objective)		not applicable	

TABLE 2 (Continued)

Water Bodies	Little Campbell River and tributaries	Mahood, Hyland and Latimer Creeks	Serpentine River	Nicomekl River	Anderson and Murray Creeks	Boundary Bay
Designated Water Uses Characteristics	Aquatic life, wildlife, irrigation, livestock watering, primary contact recreation	Aquatic life, wildlife, irrigation, livestock watering	Aquatic life, wildlife, irrigation, livestock watering	Aquatic life, wildlife, irrigation, livestock watering	Aquatic life, wildlife, irrigation, livestock watering	Aquatic life, wildlife, primary-contact recreation
pH[4]	6.5 - 8.5	6.5 - 8.5 or 0.2 maximum increase (upstream > 8.5)				not applicable
Total Lead[5]	not applicable			0.005 mg/L average 0.010 mg/L maximum	not applicable	
PCBs [6],[7],[8]	Not applicable	0.001 µg/L maximum in water 0.03 µg/g (dry-weight) maximum in bottom surface sediments 0.1 µg/g (wet-weight) in whole small fish subject to predation 0.5 µg/g (wet-weight) in muscle of larger fish consumed by man		not applicable		0.03 µg/g (dry-weight) maximum in bottom surface sediments

Note: The objectives apply to discrete samples from all parts of the waterbodies, except from initial dilution zones of effluents. These excluded initial dilution zones are defined as extending up to 100 m downstream from a discharge, and occupying no more than 50% of the stream width around the discharge point, from the bed of the stream to the surface. These excluded initial dilution zones in the Bay are defined as extending up to 100 m horizontally in all directions, but not to exceed 25% of the width of the waterbody.

[1] The geometric mean, median, and the 90th percentile are calculated from at least five samples taken weekly in a period of 30 days. The recreation objective (200-400/100 mL) applies during the recreation season and the irrigation objectives (1000-4000/100 mL) applies during the irrigation season.

[2] The increase (in mg/L, NTU or %) is over levels measured at a background site or at a site upstream from a discharge or series of discharges and as close to them as possible, and applies to downstream levels. In Boundary Bay, "control" samples should be obtained from areas of similar physical characteristics to those areas where measurements near a discharge are to be made.

[3] The average is calculated from at least five randomly located samples taken from natural substrates at each site on any one sampling date.

[4] Measurements can be made in-situ, but must be confirmed in the laboratory if the objective is exceeded.

[5] The average is calculated from at least five weekly samples taken in a period of 30 days.

[6] The objectives do not apply to Hyland or Latimer Creeks.

[7] The term PCBs applies to the sum of Aroclor 1242, 1254, and 1260, which may be present in water, sediment or fish.

[8] The maximum value should not be exceeded in bottom surface sediments taken in any part of the sub-basin, except in the initial dilution zones of effluents. The average of at least three replicate sediment samples taken from the same site should be used to check the objectives. Also, the objective applies only to fish of any species caught in any part of the creeks or river, including the initial dilution zones of effluents.

TABLE 3
MAXIMUM CONCENTRATION OF TOTAL AMMONIA NITROGEN FOR PROTECTION OF AQUATIC LIFE
(mg/L-N)

pH	Temp. 0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
6.5	27.7	28.3	27.9	27.5	27.2	26.8	26.5	26.2	26.0	25.7	25.5
6.6	27.9	27.5	27.2	26.8	26.4	26.1	25.8	25.5	25.2	25.0	24.7
6.7	26.9	26.5	26.2	25.9	25.5	25.2	24.9	24.6	24.4	24.1	23.9
6.8	25.8	25.5	25.1	24.8	24.5	24.2	23.9	23.6	23.4	23.1	22.9
6.9	24.6	24.2	23.9	23.6	23.3	23.0	22.7	22.5	22.2	22.0	21.8
7.0	23.2	22.8	22.5	22.2	21.9	21.6	21.4	21.1	20.9	20.7	20.5
7.1	21.6	21.3	20.9	20.7	20.4	20.2	19.9	19.7	19.5	19.3	19.1
7.2	19.9	19.6	19.3	19.0	18.8	18.6	18.3	18.1	17.9	17.8	17.6
7.3	18.1	17.8	17.5	17.3	17.1	16.9	16.7	16.5	16.3	16.2	16.0
7.4	16.2	16.0	15.7	15.5	15.3	15.2	15.0	14.8	14.7	14.5	14.4
7.5	14.4	14.1	14.0	13.8	13.6	13.4	13.3	13.1	13.0	12.9	12.7
7.6	12.6	12.4	12.2	12.0	11.9	11.7	11.6	11.5	11.4	11.3	11.2
7.7	10.8	10.7	10.5	10.4	10.3	10.1	10.0	9.92	9.83	9.73	9.65
7.8	9.26	9.12	8.98	8.88	8.77	8.67	8.57	8.48	8.40	8.32	8.25
7.9	7.82	7.71	7.60	7.51	7.42	7.33	7.25	7.17	7.10	7.04	6.98
8.0	6.55	6.46	6.37	6.29	6.22	6.14	6.08	6.02	5.96	5.91	5.86
8.1	5.21	5.14	5.07	5.01	4.95	4.90	4.84	4.80	4.75	4.71	4.67
8.2	4.15	4.09	4.04	3.99	3.95	3.90	3.86	3.83	3.80	3.76	3.74
8.3	3.31	3.27	3.22	3.19	3.15	3.12	3.09	3.06	3.03	3.01	2.99
8.4	2.64	2.61	2.57	2.54	2.52	2.49	2.47	2.45	2.43	2.41	2.40
8.5	2.11	2.08	2.06	2.03	2.01	1.99	1.98	1.96	1.95	1.94	1.93
8.6	1.69	1.67	1.65	1.63	1.61	1.60	1.59	1.58	1.57	1.56	1.55
8.7	1.35	1.33	1.32	1.31	1.30	1.29	1.28	1.27	1.26	1.26	1.25
8.8	1.08	1.07	1.06	1.05	1.04	1.04	1.03	1.03	1.02	1.02	1.02
8.9	0.871	0.863	0.856	0.849	0.844	0.839	0.836	0.833	0.832	0.831	0.831
9.0	0.703	0.697	0.692	0.688	0.685	0.682	0.681	0.681	0.680	0.681	0.682

pH	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
6.5	25.2	25.0	24.8	24.6	24.5	24.3	24.2	24.0	23.9	23.8
6.6	24.5	24.3	24.1	23.9	23.8	24.6	23.5	23.3	23.3	23.2
6.7	23.7	23.5	23.3	23.1	23.0	22.8	22.7	22.6	22.5	22.4
6.8	22.7	22.5	22.3	22.2	22.0	21.9	21.8	21.7	21.6	21.5
6.9	21.6	21.4	21.3	21.1	21.0	20.8	20.7	20.6	20.5	20.4
7.0	20.3	20.2	20.0	19.9	19.7	19.6	19.5	19.4	19.3	19.2
7.1	18.9	18.8	18.7	18.5	18.4	18.3	18.2	18.1	18.0	17.9
7.2	17.4	17.3	17.2	17.1	16.9	16.8	16.8	16.7	16.6	16.5
7.3	15.9	15.7	15.6	15.5	15.4	15.3	15.2	15.2	15.1	15.1
7.4	14.2	14.1	14.0	13.9	13.9	13.8	13.7	13.6	13.6	13.5
7.5	12.6	12.5	12.4	12.4	12.3	12.2	12.2	12.1	12.1	12.0
7.6	11.1	11.0	10.9	10.8	10.8	10.7	10.7	10.6	10.6	10.5
7.7	9.57	9.50	9.43	9.37	9.31	9.26	9.22	9.81	9.15	9.12
7.8	8.18	8.12	8.07	8.02	7.97	7.93	7.90	7.87	7.84	7.82
7.9	6.92	6.88	6.83	6.79	6.75	6.72	6.69	6.67	6.65	6.64
8.0	5.81	5.78	5.74	5.71	5.68	5.66	5.64	5.62	5.61	5.60
8.1	4.64	4.61	4.59	4.56	4.54	4.53	4.51	4.50	4.49	4.49
8.2	3.71	3.69	3.67	3.65	3.64	3.63	3.62	3.61	3.61	3.61
8.3	2.97	2.96	2.94	2.93	2.92	2.92	2.91	2.91	2.91	2.91
8.4	2.38	2.37	2.36	2.36	2.35	2.35	2.35	2.35	2.35	2.36
8.5	1.92	1.91	1.91	1.90	1.90	1.90	1.90	1.90	1.91	1.92
8.6	1.55	1.54	1.54	1.54	1.54	1.54	1.55	1.55	1.56	1.57
8.7	1.25	1.25	1.25	1.25	1.25	1.26	1.26	1.27	1.28	1.29
8.8	1.02	1.02	1.02	1.02	1.03	1.03	1.04	1.05	1.06	1.07
8.9	0.832	0.834	0.838	0.842	0.847	0.853	0.861	0.870	0.880	0.891
9.0	0.684	0.688	0.692	0.698	0.704	0.711	0.720	0.729	0.740	0.752

Source: Nordin and Pommen 1986

TABLE 4
AVERAGE 30-DAY CONCENTRATION OF TOTAL AMMONIA NITROGEN FOR PROTECTION OF AQUATIC LIFE
(mg/L-N)

pH	Temp. 0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0
6.5	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84
6.6	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84
6.7	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84
6.8	2.08	2.05	2.02	1.99	1.96	1.94	1.92	1.90	1.88	1.86	1.84
6.9	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84
7.0	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84
7.1	2.08	2.05	2.02	1.99	1.97	1.94	1.92	1.90	1.88	1.86	1.84
7.2	2.08	2.05	2.02	1.99	1.96	1.95	1.92	1.90	1.88	1.86	1.85
7.3	2.08	2.05	2.02	1.99	1.97	1.95	1.92	1.90	1.88	1.86	1.85
7.4	2.08	2.05	2.02	2.00	1.97	1.95	1.92	1.90	1.88	1.87	1.85
7.5	2.08	2.05	2.02	2.00	1.97	1.95	1.93	1.91	1.88	1.87	1.85
7.6	2.09	2.05	2.03	2.00	1.97	1.95	1.93	1.91	1.89	1.87	1.85
7.7	2.09	2.05	2.03	2.00	1.98	1.95	1.93	1.91	1.89	1.87	1.86
7.8	1.78	1.75	1.73	1.71	1.69	1.67	1.65	1.63	1.62	1.60	1.59
7.9	1.50	1.48	1.46	1.44	1.43	1.41	1.39	1.38	1.36	1.35	1.34
8.0	1.26	1.24	1.23	1.21	1.20	1.18	1.17	1.16	1.15	1.14	1.13
8.1	1.00	0.989	0.976	0.963	0.952	0.942	0.932	0.922	0.914	0.906	0.899
8.2	0.799	0.788	0.777	0.768	0.759	0.751	0.743	0.736	0.730	0.724	0.718
8.3	0.636	0.628	0.620	0.613	0.606	0.599	0.594	0.588	0.583	0.579	0.575
8.4	0.508	0.501	0.495	0.489	0.484	0.479	0.475	0.471	0.467	0.464	0.461
8.5	0.405	0.400	0.396	0.391	0.387	0.384	0.380	0.377	0.375	0.372	0.370
8.6	0.324	0.320	0.317	0.313	0.310	0.308	0.305	0.303	0.301	0.300	0.298
8.7	0.260	0.257	0.254	0.251	0.249	0.247	0.246	0.244	0.243	0.242	0.241
8.8	0.208	0.206	0.204	0.202	0.201	0.200	0.198	0.197	0.197	0.196	0.196
8.9	0.168	0.166	0.165	0.163	0.162	0.161	0.161	0.160	0.160	0.160	0.160
9.0	0.135	0.134	0.133	0.132	0.132	0.131	0.131	0.131	0.131	0.131	0.131

pH	11.0	12.0	13.0	14.0	15.0	16.0	17.0	18.0	19.0	20.0
6.5	1.82	1.81	1.80	1.78	1.77	1.64	1.52	1.41	1.31	1.22
6.6	1.82	1.81	1.80	1.78	1.77	1.64	1.52	1.41	1.31	1.22
6.7	1.83	1.81	1.80	1.78	1.77	1.64	1.52	1.41	1.31	1.22
6.8	1.83	1.81	1.80	1.78	1.77	1.64	1.52	1.42	1.32	1.22
6.9	1.82	1.81	1.80	1.78	1.77	1.64	1.53	1.42	1.32	1.22
7.0	1.83	1.81	1.80	1.79	1.77	1.64	1.53	1.42	1.32	1.22
7.1	1.83	1.81	1.80	1.79	1.77	1.65	1.53	1.42	1.32	1.23
7.2	1.83	1.81	1.80	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.3	1.83	1.82	1.80	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.4	1.83	1.82	1.80	1.79	1.78	1.65	1.53	1.42	1.32	1.23
7.5	1.83	1.82	1.81	1.80	1.78	1.66	1.54	1.43	1.33	1.23
7.6	1.84	1.82	1.81	1.80	1.79	1.66	1.54	1.43	1.33	1.24
7.7	1.84	1.83	1.81	1.80	1.79	1.66	1.54	1.44	1.34	1.24
7.8	1.57	1.56	1.55	1.54	1.53	1.42	1.32	1.23	1.14	1.07
7.9	1.33	1.32	1.31	1.31	1.30	1.21	1.12	1.04	0.970	0.904
8.0	1.12	1.11	1.10	1.10	1.09	1.02	0.944	0.878	0.818	0.762
8.1	0.893	0.887	0.882	0.878	0.874	0.812	0.756	0.704	0.655	0.611
8.2	0.714	0.709	0.706	0.703	0.700	0.651	0.606	0.565	0.527	0.491
8.3	0.571	0.568	0.566	0.564	0.562	0.523	0.487	0.455	0.424	0.396
8.4	0.458	0.456	0.455	0.453	0.452	0.421	0.393	0.367	0.343	0.321
8.5	0.369	0.367	0.366	0.366	0.365	0.341	0.318	0.298	0.278	0.261
8.6	0.297	0.297	0.296	0.296	0.296	0.277	0.259	0.242	0.227	0.213
8.7	0.241	0.240	0.240	0.241	0.241	0.226	0.212	0.198	0.186	0.175
8.8	0.196	0.196	0.196	0.197	0.198	0.185	0.174	0.164	0.154	0.145
8.9	0.160	0.161	0.161	0.162	0.163	0.153	0.144	0.136	0.128	0.121
9.0	0.132	0.132	0.133	0.134	0.135	0.128	0.121	0.114	0.108	0.102

- the average of the measured values must be less than the average of the corresponding individual values in Table 4.
- each measured value is compared to the corresponding individual values in Table 4. No more than one in five of the measured values can be greater than one-and-a-half times the corresponding objective values in Table 4.

Source: Nordin and Pommen 1986

TABLE 5

MAXIMUM AND 30-d AVERAGE NITRITE (N) CONCENTRATIONS

Chloride Concentration (mg/L)	Maximum Nitrite-N Concentration (mg/L)	30-d Average Nitrite-N Concentration* (mg/L)
<2	0.06	0.02
2-4	0.12	0.04
4-6	0.18	0.06
6-8	0.24	0.08
8-10	0.30	0.10
>10	0.60	0.20

*the 30-d average chloride concentration should be used to determine the appropriate 30-d average nitrite objective.

Source: Nordin and Pommen 1986

TABLE 6
PROVISIONAL WATER QUALITY OBJECTIVES FOR TRIBUTARIES TO THE FRASER RIVER ALONG THE NORTH SHORE

(Prepared and Issued by B.C. Ministry of Environment)

WATER BODIES	Kanaka Creek	Pitt Lake	Alouette Lake	Pitt River	Alouette River	N. Alouette River	Coquitlam River	Scott and Hoy creeks	Or Creek	Brunette River	Still Creek	Deer and Burnaby Lake
DESIGNATED WATER USES / CHARACERISTICS	Aquatic life, wildlife, drinking water (complete treatment plus disinfection), recreation, livestock, irrigation	Aquatic life, wildlife					Aquatic life, wildlife recreation, livestock, irrigation			Aquatic life, wildlife		Aquatic life, wildlife, primary-contact recreation (long-term)
		drinking water (disinfection only)		drinking water (complete treatment plus disinfection)								
		recreation		N/A	recreation							
		livestock, irrigation										
Fecal Coliforms^{1,2,3}	≤200/100 mL maximum (short-term) ≤100/100 mL 90th percentile (long-term)	≤10/100 mL 90th percentile		≤200/100 mL geometric mean (short-term) ≤100/100 mL 90th percentile (long-term)		≤100/100 mL 90th percentile	≤200/100 mL geometric mean ≤100/100 mL 90th percentile		≤10/100mL 90th percentile	not applicable		≤200/100 mL geometric mean (long-term) ≤400/100 mL 90th percentile (long-term)
Escherichia coli ^{1,2,3}	≤200/100 mL maximum (short-term) ≤100/100 mL 90th percentile (long-term)	≤10/100 mL 90th percentile		≤77/100 mL geometric mean (short-term) ≤100/100 mL 90th percentile (long-term)		≤100/100 mL 90th percentile	≤100/100 mL 90th percentile ≤77/100 mL geometric mean		≤10/100mL 90th percentile	not applicable		≤77/100 mL geometric mean (long-term)
Enterococci ^{1,2,3}	≤50/100 mL maximum (short-term) ≤25/100 mL 90th percentile (long-term)	≤3/100 mL 90th percentile		≤200/100 mL geometric mean (short-term) ≤25/100 mL 90th percentile (long-term)		≤25/100 mL 90th percentile	≤25/100 mL 90th percentile ≤20/100 mL geometric mean		≤25/100mL 90th percentile	not applicable		≤20/100 mL geometric mean (long-term)
Pseudomonas aeruginosa ^{1,3}	not applicable						≤2/100 mL 75th percentile		not applicable			≤2/100 mL 75th percentile (long-term)
Suspended Solids^{3}	10 mg/L maximum increase (upstream ≤ 100 mg/L) 10% maximum increase (upstream > 100 mg/L)											
Substrate Sedimentation^{3}	No significant increase by weight in particulate matter <3 mm in diameter										not applicable	
Turbidity^{3}	1 NTU maximum increase (upstream < 5 NTU) 5 NTU maximum increase (upstream ≤ 50 NTU) 10% maximum increase (upstream > 50 NTU)											

TABLE 6 (Continued)

<table>
<tr><th>WATER BODIES</th><th>Kanaka Creek</th><th>Pitt Lake</th><th>Alouette Lake</th><th>Pitt River</th><th>Alouette River</th><th>N. Alouette River</th><th>Coquitlam River</th><th>Scott and Hoy creeks</th><th>Or Creek</th><th>Brunette River</th><th>Still Creek</th><th>Deer and Burnaby lakes</th></tr>
<tr><td rowspan="4">DESIGNATED WATER USES
CHARACERISTICS</td><td rowspan="4">Aquatic life, wildlife, drinking water (complete treatment plus disinfection), recreation, livestock, irrigation</td><td colspan="5">Aquatic life, wildlife</td><td colspan="3" rowspan="4">Aquatic life, wildlife recreation, livestock, irrigation</td><td colspan="2" rowspan="4">Aquatic life, wildlife</td><td rowspan="4">Aquatic life, wildlife, primary-contact recreation (long-term)</td></tr>
<tr><td colspan="2">drinking water (disinfection only)</td><td colspan="3">drinking water (complete treatment plus disinfection</td></tr>
<tr><td colspan="2">recreation</td><td>N/A</td><td colspan="2">recreation</td></tr>
<tr><td colspan="5">livestock, irrigation</td></tr>
<tr><td>Total Ammonia-N</td><td colspan="12">See Tables 3 and 4</td></tr>
<tr><td>Nitrite-N[1]</td><td colspan="10">≤0.02 mg/L average
0.06 mg/L maximum</td><td colspan="2">See Table 4</td></tr>
<tr><td>Periphyton[4] Chlorophyll-a</td><td>≤50 mg/m² average</td><td colspan="2">not applicable</td><td colspan="3">≤100 mg/m² average</td><td colspan="3">≤50 mg/m² average</td><td colspan="2">≤100 mg/m² average</td><td>not applicable</td></tr>
<tr><td>Total Phosphorus[10]</td><td colspan="11">not applicable</td><td>≤0.015 mg/L (long-term)</td></tr>
<tr><td rowspan="2">Dissolved Oxygen[2]</td><td rowspan="2">8.0 mg/L minimum
11.0 mg/L minimum when embryo or larvae present (November-March)</td><td colspan="2" rowspan="2">Not Applicable</td><td colspan="6" rowspan="2">8.0 mg/L minimum
11.0 mg/L minimum when embryo or larvae present (November-March)</td><td>8.0 mg/L minimum</td><td colspan="2">6.0 mg/L minimum (short-term)
8.0 mg/L minimum (long-term)</td></tr>
<tr><td colspan="3">11.0 mg/L minimum when embryo or larvae present (November-March) (long-term)</td></tr>
<tr><td>pH[3],[5]</td><td>6.5 - 8.5 (long-term)</td><td colspan="8">6.5 - 8.5 or maximum 0.2 change (upstream <6.5)</td><td colspan="3">6.5 - 8.5</td></tr>
<tr><td>Total Chromium[2]</td><td colspan="9">not applicable</td><td colspan="3">0.020 mg/L maximum (long-term)</td></tr>
<tr><td>Total Copper[2],[4],[7]</td><td colspan="9">not applicable</td><td colspan="3">0.005 mg/L maximum (long-term) (hardness >30 mg/L)
0.004 mg/L maximum (long-term) (hardness: 20-30 mg/L)
≤0.002 mg/L average (long-term)
30 µg/g (dry-weight) maximum in sediments (long-term)</td></tr>
</table>

TABLE 6 (Continued)

WATER BODIES	Kanaka Creek	Pitt Lake	Alouette Lake	Pitt River	Alouette River	N. Alouette River	Coquitlam River	Scott and Hoy creeks	Or Creek	Brunette River	Still Creek	Deer and Burnaby Lake
DESIGNATED WATER USES / CHARACERISTICS	Aquatic life, wildlife, drinking water (complete treatment plus disinfection), recreation, livestock, irrigation	Aquatic life, wildlife					Aquatic life, wildlife recreation, livestock, irrigation			Aquatic life, wildlife		Aquatic life, wildlife, primary-contact recreation (long-term)
		drinking water (disinfection only)		drinking water (complete treatment plus disinfection								
		recreation		N/A	recreation							
		livestock, irrigation										
Total Lead[2,4,7,8]	not applicable									0.018 mg/L maximum (long-term) ≤0.004 mg/L average (long-term)		0.012 mg/L maximum (long-term) ≤0.004 mg/L average (long-term)
										0.8 µg/g (wet-weight) maximum in edible fish flesh 5 µg/g (dry-weight) maximum in sediments (long-term)		
Total Mercury[2,4,7,8]	not applicable									0.1 µg/L maximum (long-term) ≤0.02 µg/L average (long-term) 0.5 µg/g (wet-weight) maximum in edible fish flesh 0.07 µg/g (dry-weight) maximum in sediments (long-term)		
Total Zinc[2,7]	not applicable									0.03 mg/L maximum (long term) 70 µg/g (dry-weight) maximum in sediments (long-term)		
Chlorophenols[6,7,8]	not applicable			0.2 µg/L maximum in water 0.1 µg/g (wet weight) maximum in fish muscle 0.01 µg/g (dry weight) maximum in bottom surface sediments	not applicable							

TABLE 6 (Continued)

Note:

The objectives apply to discrete samples from all parts of the water bodies, except from initial dilution zones of effluents. These excluded initial dilution zones are defined as extending up to 100 m downstream from a discharge, and occupying no more than 50% of the stream width around the discharge point, from the bed of the stream to the surface. In the Pitt River, the initial dilution zone will occupy no more than 25% of th stream width, and can extend up to 100 m upstream from a discharge at times of tide reversal. These excluded initial dilution zones in lakes are defined as extending up to 100 m horizontally in all directions, but not to exceed 25% of the width of the water body. This exclusion does not apply to objectives for fish as noted below.

[1] The average, geometric mean, and the 75th and 90th percentiles are calculated from at least five weekly samples taken in a period of 30 days. For values recorded as less than the detection limit, the detection limit itself should be used in calculating the statistic.

[2] Long-term objectives indicate situations where existing water quality does not suit all desired water uses, but it is considered feasible to improve the water quality over time. Short-term objectives protect water uses to a certain degree until the long-term objectives can be achieved.

[3] The increase (in mg/L, NTU, or%) is over levels measured at a site upstream from a discharge or series of discharges and as close to them as possible, and applies to downstream levels. For substrate sedimentation, the increase is measured on the basis of the averages of at least three samples collected upstream and downstream, and the significant increase will be defined as no difference greater than 10%. In lakes, substrate sedimentation will usually be measured at the mouths of creeks where fish spawn.

[4] The average is calculated from at least five randomly located samples from natural substrates at each site on any one sampling date.

[5] Measurements can be made in-situ, but must be confirmed in the laboratory if the objective is not achieved.

[6] The term chlorophenol means the sum of tri-, tetra-, and pentachlorophenol which may be present in water, sediment or fish.

[7] The maximum value should not be exceeded in bottom surface sediments taken in any part of the sub-basin, except in the initial dilution zones of effluents. The average of at least three replicate sediment samples taken from the same site should be used to check the objective.

[8] The objective applies only to fish muscle tissue, not the whole fish or organs, of a fish of any species caught in any part of the sub-basin including the initial dilution zones of effluents.

[9] In the Coquitlam River, the objectives of ≤100/100 mL fecal coliforms, ≤100/100 mL *Escherichia coli*, and ≤25/100 mL enterococci, as 90th percentiles apply only between Coquitlam Lake and the southern boundary of the Coquitlam River Park. The objectives of ≤200/100 mL fecal coliforms, ≤77/100 mL *Escherichia coli*, and ≤20/100 mL enterococci, as geometric means and <2/100 mL *Pseudomonas aeruginusa* as the 75th percentile, apply only to the Coquitlam River below Coquitlam River Park and to Scott and Hoy creeks.

[10] The objective applies only in Burnaby Lake at a depth of 1 metre, and is the average of monthly measurements from April to October.

Source: Swain 1989

TABLE 7
NAMES AND ADDRESSES OF SPEAKERS

Report Section in Appendix	Speaker
2.1	J. Carey National Water Research Institute Environment Canada P.O. Box 5050 Burlington, Ontario L7R 4A6
2.2	J. Servizi Department of Fisheries and Oceans Cultus Lake Salmon Research Laboratory 4222 Columbia Highway Cultus Lake, British Columbia V0X 1H0
2.3	M. Nassichuk Habitat Management Division Department of Fisheries and Oceans 400 - 555 West Hastings Vancouver, British Columbia V6B 5G3
2.4	R. Girard Acting Regional Manager Environmental Protection Division B.C. Environment 1011 - Fourth Avenue Prince George, British Columbia V2L 3H9
2.5	D. Holmes Assistant Regional Waste Manager Environmental Protection Division B.C. Environment 1259 Dalhousie Drive Kamloops, British Columbia V2C 5Z5

2.6 L. Churchland
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2.14 R. McDonald
Brown and Caldwell Consultants
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Walnut Creek, California
94 596

APPENDIX

DETAILED PRESENTATION OF WORKSHOP PROCEEDINGS

HELD AT THE MING COURT HOTEL,

VANCOUVER, BRITISH COLUMBIA

FEBRUARY 21, 1990

1.0 INTRODUCTION

The Fourth Annual Fraser River Estuary Workshop on Monitoring and Research was held on February 21, 1990. The Workshop serves to provide a forum for the exchange of current information between researchers and thereby acts to facilitate coordination of future work.

The main focus of the 1990 Workshop was to consider contaminant sources to the Fraser River upstream from the estuary. Upstream sources were discussed in several presentations which reviewed information on the impacts of agricultural, municipal, and industrial discharges. The keynote address further maintained this focus in a discussion of discharges containing chlorophenols to the river. In addition, several other papers were presented which addressed topics not previously discussed in these Workshops, such as pesticide use in the estuary's agricultural areas and air quality in the greater Vancouver area.

The Workshop was well attended with over 100 participants-researchers and members of the public, from Washington State and Canada.

2.0 ABSTRACTS OF PRESENTATIONS, QUESTIONS AND ANSWERS

Most of the speakers dealt with one of three major topics; upstream contributions to the river, organic contaminants in the river, and contributions to and contaminant levels in Boundary Bay.

2.1 ORGANIC CONTAMINANTS IN THE FRASER RIVER

J. Carey[*], Project Chief, National Water Research Institute
Environment Canada, Burlington, Ontario

The Implementation Strategy of the Fraser River Management Program calls for the development of a Water Quality Plan for the estuary. Key components of the plan involve the setting of Water Quality Objectives for specific contaminants and the establishment of a monitoring program. Objectives of the monitoring program include: to establish the location, severity, extent, frequency and duration of unacceptable levels of contaminants; to assess the need for and effectiveness of remedial measures; to assess the degree to which guidelines, objectives and standards are being met and predict when they will be exceeded; and to determine the presence of hitherto unidentified or undetected problems. In July, 1985, participants at a FREMP sponsored workshop identified a number of knowledge gaps that needed to be addressed before the water quality plan could be developed. One key data gap was a lack of knowledge of actual pathways of contaminants in the estuary. The workshop recommended that pentachlorophenol (PCP) and 2,3,4,6 - tetrachlorophenol (TeCP) be chosen as benchmark chemicals to be subjected to detailed pathway research within the estuary. This presentation summarises research since the workshop on environmental pathways of organic contaminants in the Fraser River estuary.

The environmental pathways of contaminants can be subdivided into four subject areas: sources; transport; effects, including bioaccumulation; and fate. With respect to sources, the most striking result of recent studies was the episodic nature of inputs of some key chemicals. Krahn and Shrimpton (1988) found that average chlorophenol concentrations in runoff from treated lumber storage sites exceeded 100 ug/L and that plumes exceeding this concentration would occur up to 12m from shore and 60m downstream. At a river site near a point source, Hall and Jacob (1988) observed concentrations of chlorophenols that varied by more than an order of magnitude over a six hour interval with maximum concentrations of 13 ug/L. At a point on the North Arm well downstream from all point sources, Carey and Hart (1988) observed concentrations that varied by more than an order of magnitude over a twelve hour period with a maximum of 0.5 ug/L. Since these concentrations all exceed the proposed objective of 0.2 ug/L and concentrations in the plumes can exceed LC50 values for these compounds, it is evident that a monitoring program that was not capable of detecting such episodic inputs would be seriously flawed. Episodic inputs can also influence the effects of contaminants on biota. A number of reports in the literature indicate that pulse exposures of as low as 7.5 minutes of some pesticides can adversely affect the physiology and survivability of larval fish.

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[*] Keynote Speaker

Another aspect of the source question that has recently emerged is the importance of contaminant sources far upstream from the estuary. For example, chloroguaiacol loadings to the estuary of 26 to 45 kg/day calculated from the data of Carey and Hart (1988) are comparable to loadings to the river at Prince George calculated from the data of Rogers et al. (1988), suggesting long-range downstream transport of some contaminants.

With respect to transport of contaminants, one important question is the phase in which transport is occurring. It is commonly assumed that because concentrations of contaminants are in excess of three orders of magnitude higher in sediment than water, the adsorbed phase is most important. However, the importance of sorption depends critically on the relative masses of the sediment and water phases (Allan, 1986). Calculations for the Fraser River estuary indicate that under most flow conditions, transport of organic contaminants occurs primarily in the dissolved phase. However, a comparison of the calculated partition coefficients with laboratory derived values indicated that the calculations underestimate the partition coefficients of chlorophenols to Fraser River sediments by more than an order of magnitude (Carey, 1990). It was suggested that this discrepancy was due to the importance of ion pairing in chlorophenol sorption end that an important parameter for the estuary was salinity distributions.

Seasonal aspects of the salinity intrusion reported by Ages and 75 (1988) and the enhanced mixing in the area of the salt wedge that appears to occur during ebb flow (Gayer, 1985) can give rise to uncertainty about the origin of water sampled at a monitoring site. In the North Arm, Carey (1990) reported conditions more consistent with a partially mixed system than with a salt wedge. An inverse relationship between salinity and chlorophenol concentration was observed, suggesting that monitoring at sites along the North Arm might be possible, provided some correction is made for mixing with clean seawater during the tidal cycle.

Salinity may also affect contaminant bioaccumulation and effects. Carey et al. (1988) determined that bioconcentration factors for PCP and TeCP in fish from the Fraser River estuary were greater than those observed by other authors in field studies of freshwater systems but were comparable to those reported for a seawater bay. Since effects of contaminants are directly related to bioavailability, salinity could be important in determining effects of chlorophenols in the Fraser River estuary and should be taken into account in the formulation of site specific Water Quality

Objectives.

The degree of conservativeness of contaminants in an estuary can often be estimated by comparing the contaminant half-life with the hydrodynamic residence time. For the Fraser River Estuary, residence times vary from 6 to 30 hours (Ages and Woollard, 1988). Estimated degradation rates of chlorophenols in the Fraser River Estuary vary from 30 to 60 days for biodegradation and 4 to 20 days for photodegradation. Given the short hydrodynamic residence times, it is likely that the fate of chlorophenols in this system is to be transported in the dissolved phase into the Strait of Georgia.

Current monitoring programs are based on target compound analysis and generally are of limited use in detecting new contaminants. Reasonable correlations are observed between concentrations of specific contaminants in fish and water from various sites in the estuary. Thus it should be possible to determine a typical contaminant profile for a given matrix and via computerized data acquisition during analysis, report deviations from this profile. Such a program is currently in use in monitoring programs in several European countries.

In summary, research over the past few years has indicated a number of factors that should be considered in developing a monitoring program for the Fraser River estuary. These include;

- the monitoring program must be capable of detecting episodic inputs of contaminants
- site-specific water quality objectives should consider the episodic nature of the inputs
- the monitoring program should include salinity as a parameter in all analyses and attempt to correct for dilution with clean seawater during the tidal cycle

- further research is needed into salt wedge dynamics in this system and the role of salinity in contaminant sorption, bioaccumulation and effects
- upstream sources of contaminants within the basin should be given more consideration
- the identification of "typical" contaminant patterns and the development of an automatic pattern recognition system should be investigated.

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Carey. J.H. 1990. The influence of a salt wedge and tidal flow dynamics on contaminant pathways in the Fraser River, British Columbia. in Estuarine Water Quality Management, Ed. W. Michaels, pub. Springer Verlag, p. 203-211.

Carey, J.H., M.E. Fox and J.H. Hart. 1988. Identity and distribution of chlorophenols in the North Arm of the Fraser River Estuary. Water Pollution Research Journal of Canada 23: 31-44.

Carey, J.H., and J.H. Hart. 1988. Sources of chlorophenolic compounds to the Fraser River Estuary. Water Pollution Research Journal of Canada 23: 55-68.

Gayer, W.R. 1985. The time-dependent dynamics of a salt wedge. University of Washington, School of Oceanography, Special Report No. 101. 199 pp.

Hall, K.J. and C. Jacob. 1988. Bioconcentration of chlorophenols by leeches and their use as in situ biological monitors. Water Pollution Research Journal of Canada 23: 69-87.

Krahn, P.K., and J.A. Shrimpton. 1988. Stormwater related chlorophenol releases from seven wood protection facilities in British Columbia. Water Pollution Research Journal of Canada 23: 45-54.

Questions and Answers:

Q. What was the source of the contaminants? Was it all from the lumber mills?

A. Penta- and tetra- chlorophenols were fungicides used when we did our study. In fact, now, many of the mills are using TCMTB and benzothiozole based compounds, and copper 8. At the time all the mills used chlorinated phenols. Penta- and tetra-chlorophenol basically came from the lumber mills plus the pulp mills upstream.

2.2 EFFECT OF BIO-TREATED BLEACHED KRAFT MILL EFFLUENT ON JUVENILE CHINOOK SALMON

J. A. Servizi, Department of Fisheries & Oceans, Biological Sciences Branch, Cultus Lake Salmon Research Laboratory

Four bleached kraft pulp mills discharge bio-treated effluents to the upper Fraser River. Calculated effluent concentrations range from 1.5 to 3.0 percent during typical winter low flow periods assuming bank to bank dispersion. In dilution zones, effluent concentrations exceed these values. The effluents usually meet acute detoxification criteria specified by Federal Regulations and Provincial Objectives. Although unproven, it has been presumed that these criteria would provide a safe environment for aquatic life, especially the large numbers of Pacific salmon common to the Fraser River. However, chemical assays reveal residual chloro-organics, including dibenzo furans and dibenzo dioxins, in these effluents. Total organic chlorine (TOCl) levels averaged 3.3 kg/ADT in bio-treated effluents. Furthermore, juvenile chinook collected from the Fraser River contained chloro-organics of bleached kraft mill origin (chloroguaiacols, chlorophenols and dioxins), while extractable organic chlorine (EOCl) and mixed function oxidase (MFO) enzymes were elevated.

The biological implications of the above findings for chinook salmon are unknown. Although declining returns of chinook salmon to the Fraser River are believed related primarily to increased harvest, data are insufficient to determine whether kraft mill effluents exacerbate this decline. There is concern that contaminant residues and elevated MFO levels indicate chinook survival is being compromised. Accordingly, a laboratory study was conducted in the period January-August 1989. This paper reports results for the 210 day study.

Following acclimation to test apparatus and temperatures, juvenile chinook were exposed to bio-treated BKME (bleached kraft mill effluent) in the laboratory at concentrations and temperatures representative of the upper Fraser River in winter and spring. When a control group indicated smoltification had occurred, the fish were transferred to seawater free of bio-treated BKME.

At time zero and throughout the study fish were evaluated for length, weight, proximate analysis, EOCl, chloro-organic contaminants, liver MFO, serum sorbitol dehydrogenase, haematocrit, tolerance to hypoxia, liver somatic index and histopathology.

Exposure to non-lethal bio-treated BKME at environmental concentrations and temperatures led to contaminant burdens accompanied by biochemical and histological responses. However, exposures did not compromise freshwater growth, seawater acclimation or subsequent growth in seawater. There was evidence of Bacterial Kidney Disease among fish exposed to effluent in freshwater and this raises the possibility that immune competence may have been affected.

Questions and Answers:

Q. On your experiments with MFO, the liver tissue that you used, do you have any data on the concentration of, for example, 3,4,5 TCG, where you obtained a positive significant response?

A. We did not have the piece of tissue split so that part of it was used for dioxin and part for MFO. The piece of tissue is not large enough because the fish are so small. You would have to use much larger fish to do that, we are only sampling from the same group of fish.

2.3 DIOXINS IN FISH FROM THE FRASER RIVER SYSTEM

N. Nassichuk, Head, Water Quality Unit, Habitat Management Division, Department of Fisheries and Oceans, Vancouver, B.C.

Abstract not received.

Questions and Answers:

Q. Did you analyze for specific congeners of concern within isomer groups?

A. Yes, in some cases. Those data are all available in a report by Inland Waters, plus all our data are available from myself.

Q. Did you detect any of the octa-chlorinated-forms of dioxins or furans?

A. Octas are generally very low. There are data in the Environment Canada report from one of the interior mills where octa did show up. We suspect principally a possible chlorophenol source there.

In some of our data from other systems we do have some octas, not, from a toxicity equivalent perspective or human health perspective of significance. We do see some octas in some areas.

Q. Were all fish tissue types analyzed? Muscle tissue?

A. In this case all were epaxial muscle except for the juvenile chinook which were whole body. We have a variety of other kinds of tissue types in some of the marine invertebrates, crab hepatopancreas for example, but in this case it was just muscle tissue.

2.4 ENVIRONMENTAL IMPACTS FROM DISCHARGES IN THE PRINCE GEORGE AREA

R. Girard, Acting Regional Manager, Waste Management Branch,
B.C. Environment, Prince George, B.C.

While sewage and non-point source discharges to the Upper Fraser River do occur, the focus of environmental impact studies has been on the discharge of pulp mill effluent, due to the number of mills and the amount of effluent. Between 1965 and 1968, three Kraft pulp mills commenced discharging to the Fraser River at Prince George. Treatment systems have been improved over the years so that B.O.D. and suspended solids loads to the river are approximately half of what they once were, although colour load has increased.

Traditional river monitoring programs over the last 25 years have demonstrated little impact on water quality and the biological program has not shown detrimental impact on the aquatic insect community. In 1989 the monitoring program was modified to develop a more coordinated approach to assessing impact on the Upper Fraser River. The Fraser River Surveillance Committee was expanded to include both the Prince George and Quesnel mills and close communication with Kamloops was maintained in implementing an Environmental Effect Monitoring Program which is to serve as a national pilot for freshwater pulp mills. This program, developed at an "Environment Canada sponsored workshop in 1987, includes the traditional style monitoring program and adds on effluent and receiving water modules to examine chlorinated organics in water, sediments and fish.

Recent research points to a need to coordinate monitoring programs for the whole system, from the estuary to above Prince George. The onus is on the provincial and federal environmental agencies to define a mechanism to implement this coordinated approach.

Questions and Answers:

Q. Is there some place where we can get some idea of the members and Terms of Reference of the Fraser River Surveillance Committee?

A. We do have some interaction. The reports being produced down here are being sent up to us. We are intending to send copies of the minutes of our meetings to the FREMP group.

Q. Will that be available at the FREMP office?

A. I think it should already be available if it is not I will make sure you get updates of our recent minutes.

Q. When will the results of the program you outlined be available?

A. It should be available in a few months.

2.5 ENVIRONMENTAL IMPACTS FROM DISCHARGES IN THE KAMLOOPS AREA

D. Holmes, Assistant Regional Waste Manager, B.C. Environment, Kamloops, B.C.

The Thompson River watershed is broken into three sub-basins for assessment of impacts on water quality. The Shuswap Basin includes major rivers such as the Eagle and Salmon and lakes such as Shuswap, Mara and Adams. Major existing and potential environmental impacts in this basin are non-point source. Of studied concern are agricultural runoff into the Salmon River and septic leachate into areas of Shuswap Lake. Houseboats also discharge quantities of grey water into Shuswap Lake. Of unstudied, but potential concern, are forestry impacts in the Eagle River watershed and other Shuswap Lake tributaries. The only major point source discharges are the Salmon Arm STP which discharges into Shuswap Lake but now has tertiary treatment, a Federal fish hatchery which discharges into Eagle River, and the Samatosum mine which discharges into Johnson Creek, a tributary of the Adams Lake.

The Thompson-Bonaparte Basin includes the North and South Thompson and Bonaparte rivers and Kamloops Lake. This basin is the most highly developed basin in the watershed. Industrial discharges of significance are Weyerhaeuser pulp mill into the Thompson River and a Federal fish hatchery into the Clearwater River. Weyerhaeuser's impacts include increased eutrophication and some dioxin contamination while nutrient addition results from the fish hatchery. Significant municipal sewage treatment plant discharges are from Kamloops (tertiary treatment), and Clinton, Cache Creek and Ashcroft, which all have secondary treatment. Impacts from Kamloops and Ashcroft are considered minor while nutrient impacts are noted from the Cache Creek STP and Clinton lagoons. Some toxicity problems related to chlorination, now being assessed, are suspected from the Cache Creek STP. As for the Shuswap Basin, non-point sources may be of most importance in the Thompson-Bonaparte Basin. Water quality and land use assessment studies have shown major impacts from agriculture in the Bonaparte River watershed. Land use activities are impacting Deadman Creek through increased siltation, bank erosion and attendant problems, and nutrient addition. Although specific studies have not been done, increased siltation in the North Thompson River is thought to be a result of land use activities relating to forestry, road and railway construction, and land clearing.

The Nicola Basin has a small urban base but extensive agriculture and mining development. The major waters are the Nicola and Coldwater rivers and Nicola Lake, with numerous smaller rivers and lakes. The only direct municipal discharge comes from Merritt which now has tertiary treatment and lagoon infiltration. The only industrial direct discharge is the Federal fish hatchery on Spius Creek which is suspected to be causing increased eutrophication. Major mine development in the Highland Valley has resulted in major land use impacts within the valley but effluents are not discharged to waterways. Again, the real impacts in this basin are the result, mainly, of agricultural non-point discharges. Heavy agricultural development in the Upper Nicola and surrounding watersheds has resulted in deteriorating water quality in numerous streams feeding Nicola Lake. Other streams feeding the Nicola River below the lake are also impacted by agriculture. Forestry activities in the Spius Creek watershed, although not extensively monitored, may also be contributing to decreased water quality.

In the Thompson River Watershed, most problems relating to water quality deterioration are the result of non-point source pollution. Direct discharges in the basin generally have a high degree of treatment and any problems resulting from them are local. The non-point source problems appear to affect a greater area and are much more difficult to isolate and treat.

Questions and Answers:

Q. You have conducted photographic surveys on the Bonaparte and Salmon rivers. Have you collected any data which quantifies the major cattle-related problems?

A. Yes. We have reams of data. The data are not of interest to the cattlemen. We want to show them their operation from the air, usually in the winter when the impact is the greatest. When you see a few thousand head of cattle beside a stream, with the manure running into the creek, you don't argue. The Federation of Agriculture is involved in a system of review.

Q. Have any of these data been reported?

A. About three reports are available.

Q. Would the problem be lessened if all the cattle were on closed feed lots?

A. That is not a difficult problem in the Interior. It is a matter of where you place the cattle. We are not talking about spot areas, we are talking about large areas. With a small amount of education we can eliminate about 80% of the problem. There is still going to be about 20% requiring more work.

Q. Is there any action now about removing the farm exclusion from the Waste Management Act?

A. Presently there is a committee of Ministry of Agriculture and Environment staffs working to change the regulations. Our interpretation of the Act is that anything non-traditional loses the exemption. It is our decision what is traditional and therefore exempt from the Waste Management Act. When dealing with these people, it is not like dealing with an industry. There are different individuals with different beliefs. We try for education. The legal process is a last resort.

Q. You mentioned habitat destruction was a grey issue and was not being looked at.

A. From a water quality standpoint it is not being looked at. I have no data. We would like to spend more time on it. It depends on where the priorities are.

Q. You suggested the Cache Creek Landfill is anything but a non-polluter. Do you have any data to support that?

A. We have about 6,000 pages of technical reports. The water table, if you can find it, is quite deep. The water in it is the worst I have ever seen. The table moves very slowly, about one metre per year. In the Interior, we don't have leachate. We just don't get the precipitation. Once you get to Salmon Arm and east, leachate can start to occur. We have had a monitoring program on the water table for quite a few years. When I say not non-polluting, I am thinking of the impact on the water table.

Q. You did not mention contamination by wood preserving plants in the Interior. There are a number of hot spots.

A. We have a lot of wood operations in the Interior and are just starting now to investigate in more depth. The solution there is going to be incredible.

Q. Is it true that if an operation has a permit you don't get involved with monitoring the discharges?

A. All we do now is audit their results. In the past we did all the monitoring. Some larger companies would do their own monitoring. About two years ago the Government decided we would only audit.

Q. You maintain a check of whether they are following their permit?

A. Yes.

2.6 FEDERAL/PROVINCIAL MONITORING OF THE FRASER RIVER DRAINAGE

L. Churchland, Chief, Water Quality Branch, Inland Waters Directorate, Environment Canada, North Vancouver, B.C.

The Canada/B.C. Water Quality Monitoring Agreement was signed by the Federal and Provincial Ministers of the Environment in October of 1985. The overall purpose of the agreement is to provide for the coordination and integration of federal and provincial water quality monitoring activities, to allow comprehensive assessments in a cost-shared or work-shared manner. The objectives are to achieve a continuing commitment by the parties to the acquisition of water quality data, to obtain scientifically sound water quality information and to achieve compatibility between respective water quality data bases for water resource management purposes.

The current value of the Federal/Provincial agreement for 1990-91 is approximately $210,000 on the part of each government, including salaries, operating and capital costs. Of the total cost, approximately 70% goes into water quality monitoring, 15% into quality assurance, 2% into radionuclides monitoring, 10% into network evaluation, and 3% into data exchange. By far the largest category is the analytical services required.

The Water Quality Agreement consists of several components, the largest of which is the regular collection, usually every two weeks, of water quality information from 24 federal/provincial stations throughout the Province. The primary purpose of the data collection has been the determination of long-term trends, for which approximately 5 years worth of data is required before statistical analysis can be conducted. Some of the stations are located in areas which are not heavily affected by direct anthropogenic inputs, so that the data base can be used to describe the natural variability in water quality conditions, in relation to the hydrograph. Water quality stations are located, where possible, at or near Water Survey of Canada gauging stations. There will soon be the required five years of data for trend assessment, and a working group has been formed which is evaluating the various statistical tools available.

Water samples are collected by lay collectors, members of the public or employees who live near the site and are trained in sample collection by government staff. Depending on the chemical variable being measured, the water samples are sent to the National Water Quality Laboratory in Burlington, Ontario; the Conservation and Protection Laboratory in West Vancouver, B.C.; or the Zenon Laboratory in Burnaby, B.C. Depending on the location, water quality measurements can include temperature, pH, colour, turbidity, residues, conductivity, alkalinity, hardness, major ions, total metals, nutrients, phenol, coliforms, dissolved oxygen, chemical oxygen demand, tannin and lignin, and chlorophyll-a.

The Federal/Provincial sampling stations in the Fraser River watershed are located on the Fraser River at Hansard, Marguerite, and Hope; the Nechako River at Prince George; the Thompson River at Spences Bridge; and the Salmon River at Salmon Arm. British Columbia operates ten additional monitoring stations while Canada operates two additional monitoring stations in the river basin. The frequency of monitoring at these latter stations is variable, ranging from 4 to 26 times a year.

In summary, the Canada/B.C. Water Quality Monitoring Agreement is a relatively new long-term data collection program, and the tools are being developed to look for trends after sufficient data have been collected. Users can now be provided with printouts of the data at each site, and methods for easy access to machine readable data are being explored. In the future, the work done under the agreement will be evaluated, and the possibility of including monitoring of sediments and biota assessed. A workshop bringing together water quality experts throughout the Province will be held in May, 1990, to explore the information requirements for water quality assessments, according to the major water quality issues in the region.

2.6 FEDERAL/PROVINCIAL MONITORING OF THE FRASER RIVER DRAINAGE (Continued)

M. Clark, Environmental Chemist, Environmental Protection Division, B.C. Environment, Victoria, B.C.

All scientists have a responsibility to ensure that data collected and published are scientifically valid. All chemical analyses, even measuring pH, must have thorough Quality Assurance/Quality Control (QA/QC) programs in place. The worst that can happen if you ignore Q.A., is that you can have 100% meaningless data. A written QA/QC plan must be followed in every lab and occasional audits must be done.

Improvements are slowly being made for QA for the formal Federal/Provincial estuary monitoring program. Upstream of the Fraser River Estuary study area and elsewhere in B.C., a number of sites are being Monitored under a Canada/B.C. Water Quality Management Agreement. There is a QA Work Group which is in the process of issuing formal Protocols and are organizing historic records for sites under the Agreement. QA has been provided regular though limited resources. Some complications arose when the two major labs underwent major organizational change.

Through participation in the cross Canada Federal/Provincial QA round robins, the reviews of the round robin results, and results of replicate analyses, a number of problems were identified. These problems predate the restructuring of the labs.

In summary, thorough QA programs are essential, but historically have been neglected or poorly funded for Fraser Estuary programs.

Questions and Answers:

Q. I agree with the need for Quality Assurance. We have all been saying that for ten years or more. I am concerned with the privatization of labs and the media reports that indicate some of the labs that are doing the testing as recently as a year ago are among the worst in Canada. This comes at a time when we are depending more and more on industry to monitor themselves, to provide analytical results, and to call in a private party to do audits. Certain of those private parties may have analytical records worse than the people they are auditing. Is QA in place in the 1990's?

A. That problem has been recognized and remedial measures are in place. Money is being spent.

Q. Why are phenols included in the monitoring program?

A. Some provincial sites measure phenols as part of their monitoring program. Phenols are not included in the Federal/Provincial agreement.

2.7 PRELIMINARY ANALYSIS OF WATER-QUALITY CONDITIONS IN THE FRASER RIVER BASIN, LAKES AND GROUNDWATER

K. Hall, Westwater Research Centre, The University of British Columbia, Vancouver, B.C., Canada, V6T 1W5

The Westwater Research Centre is conducting a research program on sustainable development of aquatic resources in the Fraser River Basin. The product of this research will be a book. The study will not collect any new scientific information but will rely on the collection and analysis of existing data available from government and research organizations. This research program has seven main objectives.

1. clarify the concept of sustainable development and its

implications for water management in the specific context of a large river basin in a developed country;

2. develop a framework for analyzing the role of water in sustainable development;
3. illustrate the framework by application to the Fraser River Basin using readily available information;
4. make a preliminary assessment of the strengths and weaknesses of existing policies and institutional arrangements for managing water in the sustainable development of the Fraser Basin;
5. recommend ways to strengthen the policies and institutional arrangements;
6. identify and define priorities for more specific research; and
7. propose the main components of an action plan for citizens and communities.

One chapter in the proposed book will assess water quality conditions in the Fraser basin. This analysis will summarize the quality of water associated with the major hydrologic compartments of the system namely precipitation, groundwater, lakes, rivers and wastewater discharges.

Most of the quality information collected on precipitation is for the lower Fraser Valley (Faulkner, 1985; Faulkner, 1987; Environment Canada, 1990). These studies indicate that pollutants such as acidic gases (SO_2 and NO_x) and PAHs generated from combustion processes in our urban areas are having a significant impact on the quality of rainfall.

Groundwater is an important source of water for many small communities and agricultural areas within the Fraser Basin. Recent studies have demonstrated several areas of high nitrate contamination in the Lower Fraser Valley (Kwong, 1986; Kohut et. al., 1989). An analysis is being made of the well records on file in the Groundwater Section of the B.C. Ministry of Environment. Where available, data are being segregated into depth intervals (0 - 30m, 30 - 61m, and 61m) and the major quality parameters (Ca^{+2}, Mg^{+2}, Fe, Mn, alkalinity, total dissolved solids and nitrate-nitrogen) summarized and compared to drinking water criteria.

Previous studies on lakes in the Fraser River Basin have related the water quality and biological conditions of the lakes to the geological regions (Northcote and Larkin, 1956; Stockner and Shortreed, 1983). Data have been collected from these studies and from unreported information available from the B.C. Ministry of Environment to assess the eutrophication status of over 50 lakes within the Basin. This information has been graphed on a log chlorophyll vs log total phosphorus plot to show the trophic distribution of the lakes. It will be put into a GIS system to show the spatial location of these lakes within the Basin. Information on the acid sensitivity of the lakes, within the Basin, will also be put into a GIS system and related to the acid sensitivity of the soils with the Basin.

Several recent review articles have summarized water quality conditions and sources of water pollution in the main stem of the Fraser River (Northcote and Larkin, 1988; Birtwell et. al., 1988; Servizi, 1989). These reports are being reviewed and summarized along with recent data collected by the Federal and Provincial governments as part of their cooperative monitoring program on the Fraser. The Fraser River Basin has been divided into 13 sub-basins; three of these are on the main stem of the Fraser and the other 10 include the major tributaries. For many of the tributaries, data has been taken from microfiche cards and incorporated into a computer data base. These data have been segregated into high and low flow periods and include an analysis of the major cations (Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}), major anions (SO_4^{-2}, Cl^{-} and HCO_3^{-}), trace metals (Cu, Pb and Zn), nutrients (total phosphorus and nitrate-nitrogen), solids (suspended and total dissolved), and fecal coliforms. Some of these data will be displayed on a GIS system to show changing conditions throughout the Basin.

In addition to the above reports several studies have been useful in our summary of wastewater sources in the Fraser River Basin. A good overview for the lower Fraser has been published as part of the FREMP process (Hagen and Langford, 1990) and the regional reports being prepared by the B.C. Ministry of Environment on Water Quality Objectives for the province provide detailed information on the quality of effluent under individual permits.

In this review of water quality two case studies have been selected to develop a perspective on the types of water pollution problems being faced in the Fraser. The first will deal with point source pollution and will study the pulp mills in the areas of Kamloops, Quesnel and Prince George. The second case study will investigate non-point sources of pollution and will study urban stormwater runoff with particular emphasis on the Brunette River Basin which is in a highly urbanized area of the Lower Fraser.

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No questions.

2.8 REGULATION OF ANTI-SAPSTAIN DISCHARGES

P. Krahn, Project Engineer, Toxic Chemicals Group,
Environment Canada, North Vancouver, B.C.

CURRENT RESEARCH OF TCMTB

G. Kruzynski, Research Biologist, Pollution Toxicology Group,
West Vancouver Laboratory, Department of Fisheries and Oceans

TCMTB 2-(thiocyanomethylthio) benzothiazole is presently being used by the lumber industry as a replacement for chlorophenols to prevent discoloration of lumber by sapstain fungi.

The extent of leaching of TCMTB by rainfall from lumber stored outdoors has recently been established. Stormwater runoff from a modern well-operated lumber mill contained up to 480 ug/L TCMTB. Since the 96h LC50 for juvenile chinook and coho salmon is in the range of 6-17 ug/L, there is concern about potential sublethal effects on fish residing in receiving waters such as the Lower Fraser River. Since sublethal effects on fish of TCMTB and its degradation products are virtually unstudied, we are investigating a variety of physiological and behaviourial responses relevant to the survival of juvenile Pacific salmon.

Investigations include effects on oxygen consumption, gill histology, respiratory problems (as monitored by coughing rate), hydromineral balance in freshwater, sea water and during transition between the two media; neurochemistry and neuroanatomy pertinent to innate and learned behaviour. Studies are also underway to determine the potential of using chemical analysis of fish bile as a biomonitor of previous TCMTB exposure.

Annular exercise tanks are being used for flow through sublethal exposure. Behaviours being monitored include rheotaxis, current selection, schooling and cover response.

Latent effects of previous TCMTB exposure are being studied in a 4500 L experimental aquarium (Water Column Simulator). The general swimming activity and vertical distribution of schools of chinook salmon are being quantified utilizing computer-assisted video image analysis. Reactions to sharply stratified (fresh water over salt water), normoxic and hypoxic conditions are being investigated. Methods are also being developed to determine whether previous TCMTB exposure renders chinook salmon more susceptible to predation.

Information collected to date indicates behaviourial and physiological changes down to 3 ug/L TCMTB; a level below the current limits of quantification by HPLC (ie. high pressure liquid chromatography) techniques.

Questions and Answers:

Q. Did you study the effects of the carrier by comparing to a control without a carrier?

A. All these tests were done versus a carrier, so anything is relative to the carrier. The carrier at the highest concentration we tested did not have any problem with any of the parameters measured. In the low levels we see almost pure TCMTB dissolved in a little acetone in basically 18 litres of water, so there is no carrier involved.

2.9 AIR QUALITY IN GREATER VANCOUVER

H. Wallis, GVRD Pollution Control, currently of:
Policy and Planning Branch, B.C. Environment, Victoria, B.C.

GVRD Pollution Control began the preparation of an Air Management Plan for the District in September of 1988 to describe present and future air quality issues, and choices which can be made to ensure good air quality in the future. The first stage of the Plan was completed in September of 1989, and included an assessment of current and future air pollution emissions and regional air quality trends. The assessment is based on historical monitoring data and a detailed inventory of 1985 air emissions which is projected 10 and 20 years into the future.

Assessment of Current Emissions and Air Quality

The inventory of 1985 emissions contains information on all mobile, point, area and gasoline marketing sources of five contaminants. Approximately 75% of all regional emissions are from motor vehicles. Projected future emissions are based on growth predictions for the region, and the assumption that regulatory programs in the District continue at the existing level of stringency.

Air quality data from the past eleven years shows either a decrease or a level trend for all pollutants measured. Air quality is Good more than 95% of the time compared with federal objectives (less than the federal Maximum Desirable objective, or an Air Quality Index of 25). Exceptions are due to carbon monoxide, particulate or ozone levels, when meteorological conditions are unfavourable for dispersion of pollutants.

Projections of Future Emissions and Air Quality

Overall, emissions in the District are expected to decrease to 1995, due mainly to the influence of more stringent federal standards for new vehicle emissions. Projected regional growth in the decade leading to 2005 is expected to partially reverse the decrease in regional emissions to 1995. Significant decreases are projected in the emissions of carbon monoxide and hydrocarbons. Increases in suspended particulate and sulphur oxides are also projected, unless mitigating actions are taken. Future regional air quality levels are expected to reflect the general trend in emissions described above.

Future Work

An action plan based on the Stage 1 report has been adopted by the GVRD Board of Directors. This plan proposes actions which can be taken in the near future to address regional air quality issues, identifies areas which require further study, and outlines a framework to solicit input from the public, industry and government. Among the actions proposed are cooperative work with industry and other levels of government on a motor vehicle emission inspection and maintenance program and emission reductions from the gasoline refining and marketing sector. These efforts are being coordinated with other government programs, such as the federal NO_x/VOC Management Plan.

Future work will result in the formulation of an Air Management Plan for the District which addresses the issues identified in Stage 1, and will specify actions which can be taken to ensure that the District and areas downwind enjoy good air quality in future years.

This work is summarized in a 10 minute video: "Challenges and Choices Protecting our Future Air Quality", available from GVRD Pollution Control by calling 436-6700.

Questions and Answers:

Q. You are looking at total particulate. Have you ever looked at what is in the particulate?

A. There has been a limited-amount of investigation into the composition of the particulate: At ten of our stations analyses for a package of heavy metals is done. A small amount of PAH work was done about 5 years ago, suggesting our levels were reasonably low. Work done in Seattle in the last few years has led them to a wood stove curtailment program during periods of poor dispersion, based on PAHs in particulate. Even though regionally there is not a PAH problem, there are "hot spots' in residential districts where there is heavy use of wood stoves and fireplaces. Somewhere in 1990/91 we will look at that question again and do some PAHs and organics in particulate.

Q. You said 75% of the general loading is from cars. What kind of linkage is realistic In the near future with B.C. Transit to upgrade the transit system?

A. This seems to be the "Green Decade". People seem interested in at least talking about things they were not at all interested in even two years ago. B.C. Transit has come to the GVRD to ask about information that is available to show the benefits of transit from an environmental point of view. B.C. Transit is attending planning symposia. They are actively pursuing from their end environmental ways of promoting transit. This certainly fits in with our idea that transportation emissions must be reduced. We are not focused specifically on transportation as the be-all and end-all solution, we are interested in all kinds of solutions, including reducing the emissions of what is out there. For example, telecommuting and the kinds of things people do in Los Angeles involves working at home one day a week and taking home modems and computers. That cuts down 20% of your commuting right there. There is a lot more active engaged discussion between GVRD and Transit than there has been before.

Q. Is this all at the discussion level or are there actual plans?

A. I think the place where it all comes out is In the "Transportation Plan for B.C." that came out last year. Originally the plan called for $1 billion to be spent on highways. The Provincial Government, under pressure, turned it around to say we need $1 billion spent on transit instead. That is where it is starting to come together. However, there is nothing concrete at this time.

2.10 EFFECTS OF PRECIPITATION ON WATER QUALITY CONDITIONS IN KANAKA CREEK

P.H. Whitfield, Inland Waters, Environment Canada, Vancouver, B.C.

This project has as a general goal the development and application of instrumentation and procedures to allow water quality data to be gathered in an effective and efficient manner. In support of this goal, instrumentation is being tested and evaluated with respect to quality assurance, and length of deployment between servicing. To this end, Water Quality Branch currently operates and maintains two electronic monitoring locations. These sites are located at the Bell-Irving Hatchery in Kanaka Creek Regional Park, and at the Tynehead Hatchery in Tynehead Regional Park. In-stream measurements of temperature, conductivity, pH, dissolved oxygen, depth, and Oxidation Reduction Potential are made every fifteen minutes and logged for retrieval over phone lines. Data are downloaded at least once per week.

In conjunction with the in-stream measurement each site is also equipped with an electronic weather station. Measurements of air temperature, relative humidity, photosynthetically active radiation and rainfall are logged at 15-minute intervals.

These headwater streams respond quite rapidly to rainfall events. Kanaka Creek is an uplands, largely forested area with shallow acid soils. In contrast, the Serpentine is largely grassed, with more alkaline soils. Both systems show pH responses to rainfall events. In order to better evaluate the effect of rainfall on streams several events are monitored each year. These studies consist of extensive sampling of the streams during a storm event, with subsequent chemical analysis to determine the effect of storms on stream chemistry.

Some published results from work at Kanaka Creek:

Dalley, N.E.,1986. High Frequency Water Quality Monitoring of a Coastal Stream. In: Statistical Aspects of Water Quality Monitoring. Developments in Water Science Vol 27. 433-442.

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No questions.

2.11 CONTAMINANTS IN BOUNDARY BAY SEDIMENTS AND FISH

L.G. Swain, Supervisor, Water Quality Studies, Water Management Division, B.C. Environment, Victoria, B.C.

The B.C. Ministry of Environment, through the Fraser River Harbour Commission, conducted a survey of sediments, benthos and fish from Boundary Bay during June 1989. Samples were analyzed at the Analytical Services Laboratory in Vancouver for metals, PAHs, organochlorine pesticides, chlorinated phenols, PCBs, and phthalate esters. This paper will examine values of the measured organic contaminants.

Sediment samples were collected from ten sites within the Bay. At each site, five samples were collected at low tide, if possible. At the five sites opposite the pump stations, samples were collected along a traverse from the pump station, every 50 metres starting 50 metres from the pump station. The top 2.5 cm of sediment was scraped from an area of 15 cm by 15 cm. At the offshore sites, samples were collected using a Peterson dredge.

Clams were collected from two sites opposite the pump stations at low tide. Fish were collected at two sites using an otter trawl at a deep site and beach seines at an inner channel site.

At the two sites opposite the pump stations where clams were collected, the only organic contaminant found in both the clams and the sediment was bis-2-ethylhexyl phthalate. This contaminant was also found in all sediments, fish and crabs from the offshore and inshore sites. All sediment values were less than the lowest Puget Sound Apparent Effects Threshold (AET) value of 1.9 ug/g, a value where effects would be expected in benthos.

At the offshore site located near the International Boundary, the following contaminants were found in addition to the aforementioned phthalate: DDE and di-n-butyl phthalate. The concentrations in sediments were less than the lowest AET of 1.4 ug/g for di-n-butyl phthalate and 0.009 ug/g for p,p'-DDE.

Questions and Answers:

Q. You have indicated the number of contaminants but not the degree of contamination.

A. I tried to convey the degree of contaminants. I have not had enough time to analyze the data in totality. I looked at it in a very cursory manner to see if the values in the sediment are higher than the AET. If they are not, then hopefully we don't have a concern.

Q. Why did you choose organochlorine pesticides?

A. They are the ones that are going to be found. They are longer lived, they are used in the area, and have been used in the area historically.

Q. As I understand, the AETs are concentrations at which biological effects are always observed, that is why they are a threshold. If you don't put a safety factor or get some idea of what a safe level is, it is a little dubious to compare an AET straight to a no concern level.

A. My point is the AET number is not magic either. In Washington State they have reference sites that have higher numbers than the AET. Along the coast of British Columbia, in pristine areas, we have higher natural background levels than the AET. The AET has to be taken with a grain of salt.

Q. The AET have to be taken together with other bioassay-type information. In the Puget Sound case, when they use AETs to compare with concern levels, they will put a safety factor on that AET. It will not be just the AET, it will be a lower number.

A. In Burrard Inlet, for the Objectives we are proposing, we have applied, in many cases, a safety factor.

C. One thing you have to keep in mind is the interaction of all the other factors too, taken together. You can't look at one and then another, you have to look at it as a mixed bag, which is what it is.

2.12 PUGET SOUND AMBIENT MONITORING PROGRAM MARINE-SEDIMENT QUALITY

P. Striplin, Marine Biologist, Department of Ecology, Olympia, Washington

The principal goal of the marine sediment quality task of the Puget Sound Ambient Monitoring Program is to provide information on the sedimentary environment at stations located away from sources of pollution. The experimental design is an integrated effort that includes a study of the benthic invertebrate community structure, the study of toxicity of the sediments to bioassay organisms, and an examination of the sediments to determine the presence or absence of chemical contaminants.

Fifty stations located throughout Puget Sound were sampled in March 1989. Five of these stations are located adjacent to or in rough transects from the U.S. mainland to the Canadian border, two in Strait of Juan de Fuca, and three in the Strait of Georgia. Metals concentrations at stations in the Strait of Juan de Fuca were low relative to percent fines and PAH concentrations were undetected or low. In the Strait of Georgia, Station 1 in Semiahmoo Bay and Station 2 near Cherry Point also had low concentrations of metals and PAH. While Station 3 in the central Strait of Georgia had low concentrations of metals and PAH, anomalous values for beta-coprostanol and volatile organic compounds were found there. The presence of those chemicals suggests an anthropogenic source, although possible sources in that area are not obvious.

There was no significant amphipod mortality nor any significant decreases in light output using the Microtox bioassay at any of the five stations. The abundance and number of taxa at the Strait of Juan de Fuca stations (7 and 9) were very similar despite being at different water depths. Stations 1 and 3 in the Strait of Georgia had similar numbers of taxa but different abundances and Station 2 near Cherry Point had an abundance and number of taxa similar to the Strait of Juan-de Fuca stations.

Questions and Answers:

Q. Could you explain the amphipod bioassay? Were you plotting percent mortality?

A. It was the mean percent mortality among five replicates.

Q. The 44% mortality was not significant? That doesn't sound like much of a bioassay.

A. R. Schwartz said he did not consider that to be significant. When you look at the bioassays being put into use right now in Puget Sound you have the amphipod bioassay, microtox, the oyster larvae bioassay, echinoderm bioassay, and now you have a Neanthes bioassay which is close to being a chronic bioassay. Microtox is the cheapest at $250 per sample, the amphipod bioassay is next at $390. All the others are in excess of $800 per sample. The amphipod bioassay is the only one which has been thoroughly and significantly tested in many different types of environments and with many different types of grain sizes. It is the best we have right now. There is some question as to whether it is really useful. None of the other bioassays have been studied in remotely as much detail.

Q. We are doing the same types of bioassays as you mentioned. In addition to amphipod bioassays we are also having the oyster larvae and echinoderm bioassays. These are the ones that are really rejecting sediments for ocean dumping. You did not do any of these for your tests?

A. No. It was purely lack of money.

Q. I would suspect that the Elliot Bay and Commencement Bay sediments would not pass the criteria for ocean dumping.

A. I don't know.

Q. Regarding the results shown for non-polar organic contaminants, were they normalized for total organic carbon content?

A. These were dry weight, not normalized.

Q. Would it be fair to ask you to comment on the AET concept?

A. No. There is another unit in the Department of Ecology that is working specifically on sediment quality criteria for Puget Sound. While I have talked to those people, I do not know exactly what is going on. I know the Department of Ecology did deliver to the Puget Water Quality Authority draft sediment quality criteria.

Q. At the Semiahmoo Bay site that had the highest concentrations of PAHs, was that also at the 20 m depth?

A. Yes. It was 93% fines.

2.13 PESTICIDES IN AGRICULTURAL DRAINAGES ON THE LOWER MAINLAND

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A monitoring survey was conducted from 1985 to 1987 to determine the levels of agricultural pesticides: azinphosmethyl, diazinon, dinoseb, endosulfan, and fensulfothion in selected farm ditches leading to the Lower Fraser, Nicomekl, and Sumas rivers in British Columbia. In ditch water azinphosmethyl, diazinon, endosulfan, and fensulfothion were not detected (less than 1 ug/L).

Dinoseb was consistently found in ditch water for one year after the spray season at levels from 0.3 - 18.6 ug/L, averaging 4.9 ug/L. The endosulfan level in ditch water of one farm reached 1530 ug/L shortly after a spray application, even though it was not found at other times of the year. Endosulfan was consistently found in ditch sediments at all study sites at levels varying from 2 - 150 ug/kg, averaging 18.8 ug/kg. Low levels, i.e. 2.7, 4.0, 22.9 and 10 ug/kg respectively of azinphosmethyl, diazinon, dinoseb and fensulfothion were sporadically found in ditch sediments.

Further studies in 1988 showed concentrations of diazinon in water were highest in irrigation ditches inside the treatment plot, immediately after application. Lower concentrations were detected in the adjacent reservoir, waterways outside the dyke and the tributaries 100 m downstream from the treatment plot. Some residues accumulated in sediments of the irrigation ditches and the reservoir. Low levels were occasionally detected in sediments of the waterways and tributaries. Diazinon disappeared rapidly and was no longer detected in water or sediments 66 days after the second application, except in irrigation ditches. Residues were 12, 6 and 7 ppb respectively, in fruit collected 14, 21 and 28 days after the second application.

Questions and Answers:

Q. Do you have any idea of the total use of these pesticides in the Lower Fraser Valley?

A. We have some idea in terms of the total product use. That is how we derived the five pesticides, based on the total amount used per year. Unfortunately, those numbers are classified information.

Q. Why are they classified?

A. We got those numbers from various distributors, and they insist on maintaining client confidentiality.

Q. As long as you have the total number, the distribution is not crucial.

A. Yes. But if I told you the number you might ask me where they are from, so to make things simple, it will all remain classified.

Q. You mentioned that the farmers phoned you when you could go and sample, when they were going to spray the field. If you were going to check compliance with Water Quality Objectives for pesticides, how useful would it be to measure the ambient levels of pesticides in those ditches at any time without regard to when pesticides are being used?

A. When I was doing the study, I had six farmers involved. If I had more than one farmer phone me, I would have much better data now. However, I had one farmer, and based on those numbers I can tell a farmer "we have a problem here and should have a greater setback". Inspection is always difficult. The farmer is doing work on his own land, if you are lucky he will let you on.

Q. Are the Water Quality Objectives for pesticides useful? What you are talking about is a very spikey occurrence. Can you use Water Quality Objectives to check if there is a problem with farms and farm drainage. Unless you know when pesticide was being applied, what would be the value of the data?

A. The data will tell you that there is going to be a problem. I can give you the ammunition to impose regulations on the farmer spraying and for imposing setbacks.

2.14 IONA SEWAGE TREATMENT PLANT DISCHARGE DISPERSION

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Field studies were conducted in August 1988 to verify the performance of the new deep sea outfall for the Greater Vancouver Regional District (GVRD) Iona Island Sewerage Treatment Plant (STP). The Iona Island STP serves Vancouver, B.C. treating wastewater flows that range from an average dry weather flow of 4 cubic metres per second up to the maximum wet weather capacity of 17.7 cubic metres per second. Treated effluent is discharged through twin conduits Into the Strait of Georgia off Iona Island. The diffusers are 505 m long at an average depth of about 90 m.

On two days, Rhodamine WT fluorescent tracer dye was injected into the Iona STP effluent under different tidal conditions for about 3 hours. The wastewater plume was then tracked offshore using two vessels equipped with in-situ fluorometric and water quality instrumentation and accurate positioning equipment to monitor the plume's 3-dimensional location and movement. A third vessel was used for drogue tracking and bacteriological sampling.

The study determined that the effluent plume was about 40 m thick and remained trapped at least 30 m below the surface. Minimum dilutions within the mixing zone 200 m from the diffuser were generally greater than 370:1. The US EPA initial dilution model ULINE was found to predict dilutions matching field measurements reasonably; however, model-predicted trapping depths were greater than observed trapping depths.

The study results demonstrated the effluent discharge system is successfully meeting performance expectations. The validity of available US EPA mathematical initial dilution models was also tested.

Questions and Answers:

Q. Could you hazard a speculation on the ultimate fate?

A. No, although we indicate that the dilutions within 9 km or so are in the order of about 10,000:1.

Q. You did drogue studies, where did the plume move?

A. That particular example showed that the plume moved a little toward the Banks. At the start of that dye test we had a northeasterly current that did take the plume toward the shore. Then the current moved north and the drogue kept moving northward. We tracked the drogue for 12 hours.

Q. How much dye would you use for one of these tests, how many gallons at what percent solution?

A. It was about eight gallons per release. About $35,000 in two days.

Q. I assume in your predictions of both the direction the plume was likely to take, and the fact that it was not likely to surface you took account of seasonal variability and tidal variation and current etc., because your studies were for only a very limited portion of that total variability.

A. We have done comparisons with mathematical models. Personally, I feel there are some problems with it because the trapping depths are so much different than what we observed. The models show us that we are going to get the high dilutions year round. The minimum we predicted with the model was about 130:1 at the absolute worst case conditions at the highest flows and least stratification, as in April. There is a condition in the Strait of Georgia where the Fraser River comes over and creates a lens or cap that the plume cannot pass through to reach the surface. The plume should be trapped below this our predictions say at a depth of 25 m, all the time. Even if it comes up more, it will be more difficult to rise. As the effluent is discharged, it is buoyant. It is warm, fresh water going into cold sea water and it wants to surface. As it entrains water it becomes less buoyant, and at some point it becomes neutrally buoyant. When that happens it can't go up and it can't go down, so it stays.